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A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Cane Varieties:

The bearing of crop restriction on work with new cane varieties is discussed. It is pointed out that on several scores better cane varieties make claim for attention as a means of lowering the cost of production.

Irrigation:

A progress report is presented on the Waialua project of irrigation studies. Here we have a well-planned piece of work that seeks specific knowledge of the interrelated values that pertain to the application of water to the cane crop. These values vary with the type of soil. They vary with the method, amount and interval of application. They are influenced by the time of year and by the weather. Human judgment will always play a most important part in determining how and when to apply water to sugar cane fields; but there is little doubt but that by a better knowledge of the pertinent underlying values, such judgment will be materially strengthened and enhanced in practical value.

Studies on Growth of Sugar Cane in Nutrient Solutions:

The results of certain nutritional studies on the growth of the sugar cane plant that have been conducted in water and sand cultures during the past two years are presented. The following subjects are discussed: the effect of the pH value of the nutrient solution on sugar cane growth; cane growth in tap water and distilled water; cane growth in relation to acidity; the effect of varying amounts of manganese on sugar cane growth; sugar cane growth in aerated and non-aerated water cultures; the growth of Lahaina cane in aerated water cultures; and the supply of iron to the cane plant through two roots.

Phosphate Fixation:

The phenomenon of phosphate fixation in Hawaiian soils is discussed in connection with studies of the subject as conducted with the new Experiment Station

phosphate fixation outfit. A history of the development of the method is presented, together with its application to problems of fixation and fertilization. Examples are given showing the manner of employing the kit.

A Procedure for Testing Cane and Soil from the Same Areas:

A clear description is given of the way in which the Pioneer Mill Company plans to collect information bearing upon the important issue of differential fertilization for fields or parts of fields. In detail is presented the practical technique whereby each day cane, from measured portions of the areas harvested, will be weighed and kept apart for juice tests for phosphate and potash. Soil tests from the same areas are to be made by the rapid methods. There will result, during the 1935 crop, for purposes of correlative study from over 1,000 sample areas representing about 500 acres of cane land, information on yield per acre, quality of cane, and phosphate and potash content of both soil and cane juice. The plan impresses one as definitely progressive, reaching into the practical possibilities of differential fertilization in a manner both effective and comprehensive.

A Fertilizer Policy Based on Field Experiments:

The bearing of an extensive series of field experiments at the Pioneer Mill Company on the development of the present day fertilizer practices is set forth in a detailed way. The fertilizer question has been approached from the standpoint of the several soil types to be dealt with. The requirements of nitrogen, phosphates, and potash have been studied with regard to the maintenance of the proper degree of balance between these plant essentials. The field experiments have been supplemented by determinations of phosphates and potash in cane juice. The article forms a comprehensive review of a long and valuable program of work.

Present Trends in Fertilization:

Certain important points are brought out with respect to each of the three main plant foods in their relation to present trends in fertilizer practices, whereby the individual needs of individual areas is being closely sought.

Fertilizer Schedules:

By way of correcting our previous presentation, the fertilizer schedules of the Oahu Sugar Company are shown in better and more complete form.

Hogpens:

An improved type of pen for the hogs of plantation laborers is shown.

Variety Problems in Relation to Crop Restriction

In view of the fact that the Hawaiian sugar industry is already able to produce more sugar than it is permitted to ship under the present crop restriction measure, we are obliged to ask ourselves whether the program of cane breeding and seedling testing as it is now being carried on by the Station and by the plantations is justified, and if not, what changes are required to meet the new situation.

In the past it has been possible to combat rising costs by increasing production. This mode of defense has been particularly effective when an increased yield entails no increased expenditure, as when a good variety of sugar cane is replaced by a better one.

With production restricted by law, the center of interest shifts from the problem of profit or loss per acre to one of profit or loss per ton of sugar. What is the relationship of improved varieties to the new situation?

Fifty years ago the old Lahaina variety occupied nearly every acre of land devoted to sugar cane in the Territory. Had Lahaina not been replaced by superior canes it is doubtful whether the Hawaiian sugar industry would have survived its infancy. If the present emergency finds this industry equipped with reasonably satisfactory sugar cane varieties it is in consequence of the efforts which have been exerted toward this end during the past thirty years.

We may grant that the greater the economic pressure the greater the need for varieties capable of producing sugar at low cost. We are, nevertheless, obliged to face the fact that anything we may be doing today in the direction of developing superior canes can offer no hope of reducing the cost of the 1935 or even the 1936 crops. Considering only the results to be realized within the three-year restriction period, a good case could be made for a policy of discontinuing for the time being all effort and expenditures relating to variety testing. It is certain that immediate costs could be reduced by such a procedure. However, if it is true that the present varietal resources of the plantations are the results of past efforts, it is equally true that those of the future depend upon the efforts of today.

Cane Breeding Objectives Under Crop Restriction

The breeding program has had as its goal the development of varieties capable of producing a maximum profit per acre under the various conditions of the Territory. It may be of interest to consider whether the specifications to which a good cane must conform remain valid as the goal is shifted from one of maximum profit per acre to one of maximum profit per ton of sugar allotted.

Sucrose Content has a definite bearing on profit per acre. It is even more intimately related to profit per ton of sugar. Under crop restriction, therefore, it assumes increased importance.

The development of improved hand refractometers and convenient juice sampling punches has greatly facilitated the determination of juice quality in the testing of new seedlings. It is now feasible to obtain sufficient juice data to eliminate in the early stages of testing the seedlings which are subnormal in this respect.

High Yielding Ability: At first glance it might appear that under the new situation less importance is to be attached to high yield per acre since we now have at our disposal more acres than are necessary to produce the allotted tonnage. Upon closer examination, however, we are reminded that many of the costs connected with the growing of a cane crop are *per acre* costs. This category includes plowing, planting, irrigation, cultivation, and rentals. To a considerable degree fertilization costs are also per acre costs. The *per ton* cost of these items increases as the per acre yield decreases.

A rough calculation may serve to illustrate the point. Let us assume a figure of $100 per acre as the cost of cultivation, irrigation, and fertilization, and nine tons of sugar per acre as an average yield. One hundred thousand acres would then be required to satisfy a 900,000-ton quota. If, through the substitution of superior varieties, the average yield could be increased to 10 tons per acre, only 90,000 acres would be needed to produce this quota. The consequent elimination of 10,000 acres from cane cultivation, with costs at $100 per acre, would result in a saving of $1,000,000. This figure does not include the additional savings which result from concentrating the production on the more efficient lands. It is clear then, that high yielding ability remains an important consideration in cane breeding even under restriction.

Several other varietal characteristics which assume increased importance under crop restriction may be listed as follows:

Strong Ratooning, Fast Closing In: The superiority of certain of the new seedlings with respect to these qualities has been established by plantation experience. As compared with some of the seedlings of POJ derivation, H 109 must be classed as a relatively weak ratooner, slow in closing in, and often necessitating an undue amount of replanting. The POJ 2878 seedlings—31-1203 and 31-1389—are both superior to H 109 in these features.

A reduction of ten dollars an acre in replanting and weeding costs would save the industry over a million dollars a year. There can be no doubt that savings as large or larger than this will be realized when each acre in the Territory is planted to the variety best suited to its conditions.

Efficient Utilization of Soil Moisture and Plant Foods: Certain of the seedlings derived from hardy parentages are less exacting in their water requirements than are the older varieties. POJ 2878, for example, proved superior to H 109 under the conditions of water shortage which prevailed in central Maui during the past two years. 28-1864, a half-sister of POJ 2878, is superior even to the Java cane under the extremely dry conditions of the makai unirrigated lands of the Hamakua and Kohala districts. There are also indications that some of the newer seedlings may have the advantage of lower fertilizer requirements than the older varieties. Fertilizer experiments bearing on this question are now under way on some of the plantations.

Harvesting and Transportation Costs: In the past we have been obliged to resort to small-stalked canes of the Uba type on the poorer lands of the unirrigated districts because we had no canes of fair stalk size which possessed sufficient vigor to succeed under these unfavorable conditions. These small-stalked trashy canes are objectionable because of their high harvesting and transportation costs.

The crossing of POJ 2878 with Uba-H 456 blood now promises to give us a new race of seedlings which combine the hardiness of Uba with the large-stalk size, easy trashing and superior juices of the noble canes.

Plantation Policy Under Crop Restriction

To those of us who are concerned with the problem of developing better canes it is gratifying to note that crop restriction has brought about no abatement of interest in variety testing. Some of the unirrigated plantations have curtailed their planting as an economy measure. Almost without exception, however, these plantations have set aside fields for the testing and spreading of new seedlings of promise. The wisdom of such a policy is apparent. It is only by taking full advantage of this interim to test the available seedlings of promise and to build up a seed supply of those which have demonstrated their superiority that a proper choice of varieties can be made when the normal planting schedule is resumed.

A. J. M.

Notes on the Waialua Irrigation Investigations

By H. R. Shaw and J. A. Swezey

The realization of a high degree of irrigation efficiency, as reflected in a reduction of labor and in conservation of water, requires not only a knowledge of the gross requirements of the plantation as a whole but also an intimate knowledge of the water requirements of individual fields and of the demands of the cane plant, both in regard to quantity and time, for irrigation applications.

The Waialua Agricultural Company, Ltd., and the Experiment Station of the H.S.P.A. have undertaken a cooperative investigation with the object of adding to the knowledge of the irrigated plantations of Hawaii certain fundamental relationships between the sugar cane plant, the soil type, and the amounts and time of irrigation applications as studied under actual field conditions. This paper describes the plan and the early results of this investigation.

The plantation of the Waialua Agricultural Company, on the northern slope of Oahu, comprises normally 10,200 acres of irrigated cane land extending from sea level to an elevation of 750 feet. The residual volcanic soils above the 100-foot contour, about 68 per cent of the cultivated area, range in color from light red to dark brown, and are on an average slope of approximately 6 per cent. The remaining area, about 3,200 acres, on the coastal plain below the 100-foot contour consists of stream and marine alluvial deposits on an average slope of 2 per cent. The land surface of the entire area is cut by many deep gulches and dry ravines running in a general northwesterly direction. Prevailing winds are from the northeast. Rainfall averages 40 inches per year over the entire plantation. The distribution of rainfall is dominated more by the distance from the main ridge of the Koolau Mountains, extending from north to south at an elevation of 2,500 feet, than by altitude or other factors.

The entire plantation is under irrigation, averaging approximately 32 irrigations per crop of 23 months. More than 3,000 acres are entirely dependent on gravity water supplied from four watersheds having a combined storage capacity of 2,700 million gallons. The remaining area is supplied by steam and electric pumps with a combined output of 100 million gallons per day, supplemented for a portion of the year by gravity water. During periods of water shortage, and even of normal summer supply, the problems of efficient water distribution, frequency of application, and conservation of the gravity supply become acute.

In order to formulate an irrigation policy which would insure an adequate and proportionate distribution of irrigation water to all divisions of the plantations, three phases of investigational attack seemed necessary:

I. Measurement between divisions of the plantation of the water delivery on each supply canal in order to provide an exact and impartial basis for equitable distribution of the available supply.

II. A survey of the moisture-holding characteristics of the various soil types comprising the cultivated area of the plantation.

III. Field studies on the relation of soil moisture to the rate and extent of cane growth as influenced by soil type, weather variation, age of cane, and similar factors on various portions of the plantation.

I. Water Measurement

The program of water measurement has been in operation for two years. Measuring stations are situated at strategic points on each supply canal so that the delivery of irrigation water between plantation divisions is known at all times. Parshall measuring flumes equipped with water-level recorders are the type of control most generally used.

A water balance, showing the total irrigation water received, delivered, and consumed daily by each plantation division, is maintained. Weekly reports, giving the relation of area irrigated, water consumed, and number of men irrigating in each division, show the gross water requirement and labor efficiency in each area. In addition, measurements of water to selected field areas provide a guide to the net water requirements in various sections, and indicate the magnitude of seepage and evaporation losses between the point of delivery and entrance to the field.

II. A Survey of the Moisture-holding Properties of Plantation Soils

It is generally recognized that the ability of a soil to retain moisture is governed by the size and number of soil particles. A coarse-grained sand, for instance, will retain considerably less water than the finely divided soil particles of a clay or loam. It is perhaps not so widely realized that the same forces which tend to hold a greater amount of water around the soil particles also operate to withhold moisture from the action of surface evaporation and plant root feeding. Hence, although a clay soil will hold more moisture than the same volume of sand, the clay also holds moisture more strongly around the soil particles, and a greater proportion of the total soil water is unavailable to the plant.

Extensive experimentation on the mainland United States and in Hawaii has satisfactorily established the fact that each soil type has a definite capacity for water and an equally definite soil moisture percentage below which no plant is able to withdraw moisture at a rate sufficient to maintain normal growth. The upper limit of this zone of available soil moisture is commonly termed the Maximum Field Capacity; the lower limit is called the Wilting Percentage or Wilting Point. It is readily seen that a knowledge of the total amount of moisture in the soil at any time is valueless to the field man unless the amount of that water actually available to the plant is also known.

The problem involved in the second phase of the Waialua investigations was to determine the limits and amount of soil moisture available for plant growth in the various soil types represented on the plantation. The time and equipment which would have been required to make direct determinations of these factors on a sufficiently large number of samples to warrant confidence in the results were out of the question. However, it has proved possible to use a single-value soil moisture constant which may be obtained readily and inexpensively on a large number of

samples and which provides a direct measure of the relative moisture-holding properties of the soil and an indirect measure of the upper and lower limits of soil moisture available for plant growth. This constant, termed the Moisture Equivalent, has proved to be a rather sensitive and reliable index of the variation in physical properties of the soil not only over a wide range of soil types found in a large district but also in smaller variations occurring within a single field.

Some twenty-five years ago, investigators of the United States Department of Agriculture attempting to find a simple measure of the physical properties of soils, discovered that a consistent and reliable index of relative moisture-holding power was obtained by saturating small samples of soil, subjecting them to a constant centrifugal force in order to drive off excess water, and determining the per cent moisture retained by the soil. The same investigators learned, by determining the soil moisture percentage at the time various plants wilted, that for all soil types used in their investigation there was a constant and definite ratio between the soil moisture content at permanent wilting and the Moisture Equivalent. The ratio found in this first investigation on soils obtained chiefly from the Atlantic seaboard was 1.84, regardless of the species or age of plant used. Later investigations on the Pacific Coast demonstrated that, although the basic conception was sound, for soils of different origin and of different chemical composition the ratio of $\frac{\text{Moisture Equivalent}}{\text{Wilting Percentage}}$ might differ considerably from the simple 1.84 constant.

During the period 1928 to 1930, similar studies were made on the physical and moisture-holding properties of a number of widely different soil types from irrigated plantations on the islands of Oahu, Maui, and Kauai. For all soils studied, there was a remarkably consistent relationship between the Moisture Equivalent, the Maximum Field Capacity and the Wilting Percentage. This relationship may be expressed as:

$$\text{Maximum Field Capacity} = \text{Moisture Equivalent} \times 1.1$$

$$\text{Wilting Percentage} = \frac{\text{Moisture Equivalent}}{1.2}$$

It is now felt that for soils of similar origin or from similar geographic districts, the Moisture Equivalent may be considered a reliable index of soil moisture retentiveness and of the amount of water available to the plant in various soil types. Whenever possible, however, it is advisable to check by direct determination the per cent soil moisture retained by a soil shortly after irrigation and the per cent soil moisture at which plant growth is checked or handicapped by an inadequate supply of moisture.

In undertaking the plantation soil survey based on the Moisture Equivalent, each field was sampled soon after harvest. A road, ditch, or similar well-defined boundary was taken as a base line, and sampling points established every 300 feet at right angles to the base line. Truly random samples were thus obtained with one sampling point for each two acres of land. Separate samples of surface soil and subsoil were obtained at each point, and field notes on surface slope, soil color, etc., were recorded. The Moisture Equivalent determinations were made at the Waipio soils laboratory of the Experiment Station.

The results from the laboratory determinations were classified in the following arbitrary groups and charted on a map of the plantation:

Moisture Equivalent Class	Probable Value of Maximum Field Capacity	Wilting Percentage	Probable Range of Available Soil Moisture
25.0% and less	27.5% and less	21.0% and less	6.5% and less
25.0 to 30.0	27.5 to 33.0	21.0 to 25.0	6.5 to 8.0
30.0 to 32.5	33.0 to 36.0	25.0 to 27.0	8.0 to 9.0
32.5 to 35.0	36.0 to 38.5	27.0 to 29.0	9.0 to 9.5
35.0 to 40.0	38.5 to 44.0	29.0 to 33.5	9.5 to 10.5
40.0 to 45.0	44.0 to 50.0	33.5 to 37.5	10.5 to 12.5
45.0 and over	50.0 and over	37.5 and over	12.5 and over

The survey, which is now practically completed, has contributed valuable basic information on the variation of soil types over the plantation area. It has demonstrated that the area of the plantation may be divided into definite soil groups, determined by their origin and degree of weathering, each of which has definite characteristics of moisture retention and physical structure. (See Fig. 1.) Very briefly, these soil groups may be defined as follows:

Group I. *The Mountain Belt*—extending from the 550-foot contour to the upper limits of the plantation, and from Waimea to Kemoo. Characterized by high moisture-holding capacity, Moisture Equivalent value from 35 to 45 per cent, available soil moisture from 10 to 12 per cent. Deep and uniform as to depth and area.

Group II. *The Middle Belt*—extending from the 300-foot contour to the 550-foot contour, and from Waimea to Kemoo. Characterized by good moisture-holding capacity, Moisture Equivalent value from 30 to 35 per cent, available soil moisture from 8 to 10 per cent. Fairly deep and uniform on plateaus, rather shallow top soil and low retentiveness on palis and ridges.

Group III. *The Lowland Belt*—extending from the 100-foot to the 300-foot contours, and from Kawailoa to Kawaihapai. Characterized by low moisture-holding capacity, Moisture Equivalent value from 25 to 35 per cent, available soil moisture from 6.5 to 9.0 per cent. Evidence of erosion and shallow top soil throughout, very low retentiveness on ridges and palis. Marked by heavy rock deposits and diverse soil type distribution, especially in upper Ranch to Kawaihapai. Apparently the upper edge of an alluvial fan.

Group IV. *The Coastal Plain*—extending from sea level to the 100-foot contour and from Opaeula to Kawaihapai. Characterized by high moisture-holding capacity, Moisture Equivalent value from 35 to 45 per cent and greater, available soil moisture from 10 to 14 per cent. Chiefly alluvial deposits from uplands and marine deposits from old high-level seas. Variable depth and uniformity, often broken by old coral beds.

Group V. *The Beach Belt*—a limited and broken area close to sea level. Characterized by very low moisture-holding capacity, Moisture Equivalent value 25 per cent or less, available soil moisture 6.5 per cent or less. Chiefly old beach lines and coral outcrops.

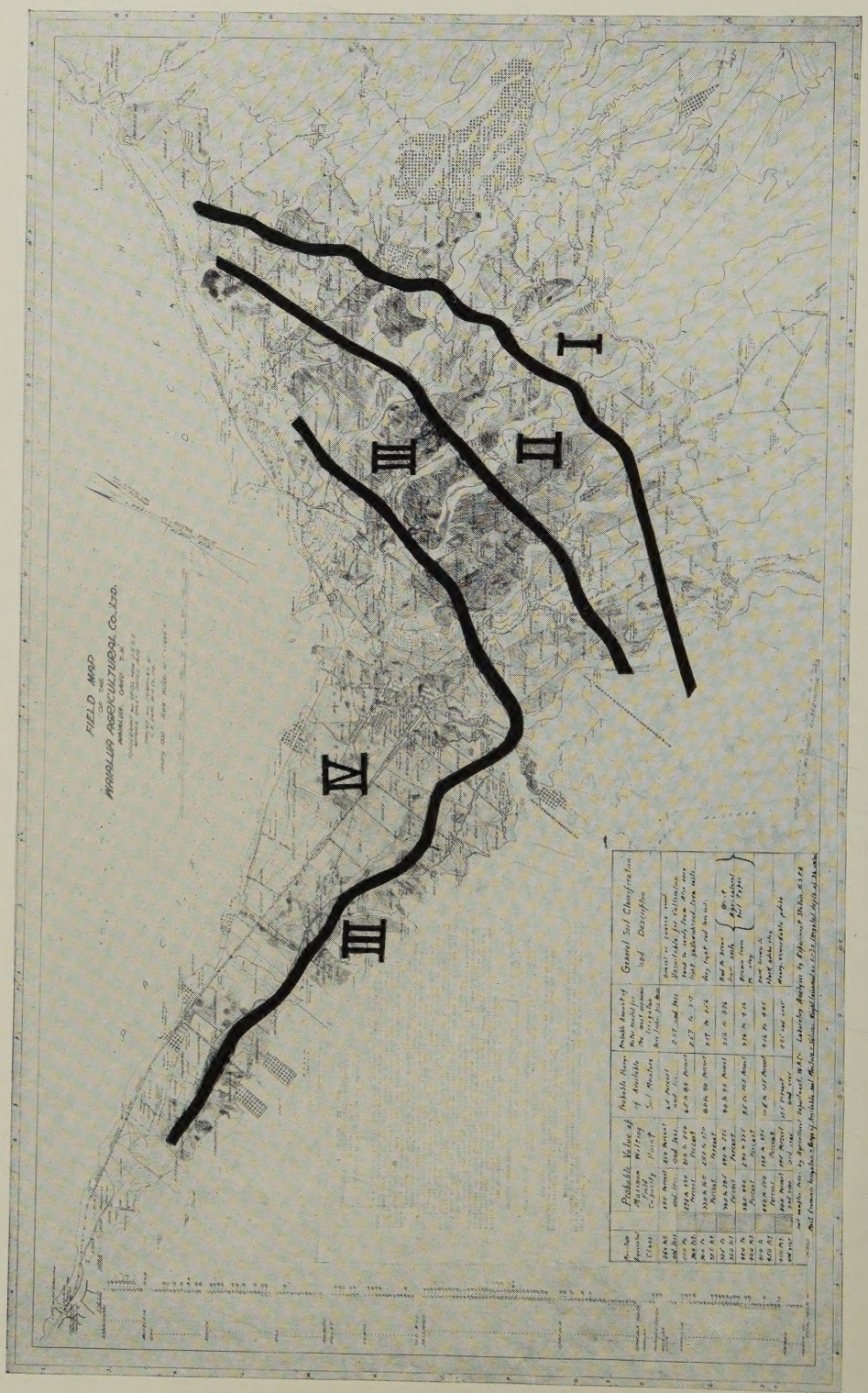

Fig. 1. Soil map based on Moisture Equivalent survey indicating the ability of various soils to retain moisture.

It should be understood that this soil classification is not necessarily a reflection of the productivity or fertility of the areas described, but pictures rather sensitively the physical and particularly the moisture characteristics and limitations of the soil. Other things being equal, a soil in Group III might well produce as much or more sugar per acre as a soil in Group I or II, but it would require more frequent applications of water to maintain the same rate of growth.

The Moisture Equivalent survey provides an effective background and a useful tool in a number of plantation and general operations. It reflects remarkably well the generally accepted geological history of this district. It provides a basis for the rational distribution of irrigation waters based on the retentive capacity and the band of available soil moisture on various areas, and indicates localized areas within fields which require special irrigation treatment. Lastly, it establishes a basis by which the results of studies on the response of cane growth to water may be safely extended to similar soil types in larger field and divisional areas.

III. Field Studies on the Relation of Soil Moisture to the Rate of Cane Growth

The object of the third phase of the Waialua investigations is an attempt to learn more precisely the effect of weather variations, soil type, age of cane, and similar factors on the interval permissible between irrigation applications if uninterrupted growth is to be maintained.

The past fifteen years have seen considerable progress made both in more efficient methods of applying water to the land and in a more exact and scientific basis of distributing the water to fields. The early work of Allen at Waipio, the Waimanalo investigations, the Ewa type of interval test on Oahu, Kauai, and Maui, the Waipahu studies on soil moisture, and the Aiea investigations have all contributed to a keener understanding of the value of irrigation water as a growth factor under varying environmental and cultural conditions.

The Experiment Station of the H.S.P.A., during the past eight years, has undertaken studies of the fundamental relationships existing between the cane plant, water and the soil. The studies began with research in the laboratory and greenhouse on the physical nature and moisture properties of certain Hawaiian soils, and on the manner in which sugar cane and other plants grown in small containers responded to soil moisture under carefully controlled conditions. The results of these findings were then applied on a larger scale to cane grown to maturity in large tanks of soil in which moisture conditions could be kept under control and in which the response of cane growth to water throughout the life of the plant could be closely studied. Finally, the accumulation of evidence gained was applied to large field plots under natural conditions. The sequence of results was consistent and logical, and the basic principles which applied to small masses of soil and to immature plants in the greenhouse were demonstrated with the normal cane crop grown in the field environment. Naturally the final step in this series of progressive studies would be to apply the results of the experimental phases of the work to commercial utilization under plantation conditions and in large scale production. This application of experimental results is now being attempted in the third phase of the Waialua investigations now in progress.

The basic relationships which were well established in the experimental studies may again be summarized as follows:

1. Each soil type has a definite capacity for water, termed the Maximum Field Capacity. A unit volume of soil, after irrigation, cannot retain more or less than this definite amount. Hence, the most efficient irrigation is one which fills to Maximum Field Capacity the soil area to the depth of the feeding roots. A heavier application of water results in penetration below the root zone from which it may never be recovered; less water results in an inadequate supply to the deeper roots.

2. After irrigation cane growth is at a relatively constant rate, affected only by season and possibly by age of cane, until the soil moisture has been depleted by root feeding to a point commonly called the Wilting Percentage at which cane growth is definitely checked and is not resumed until additional water is added to the soil.

3. The value of the Wilting Percentage is dominated by the soil type and does not change with the species or variety of crop, the season or the age of the plant. Hence, the most efficient interval between irrigations is one which replenishes the moisture supply shortly before it is depleted to the Wilting Percentage.

4. In both pot experimentation and in field tests, it has been impossible to detect from the appearance of the soil surface or from the appearance of the leaves or stalk of the cane plant when the Wilting Percentage has been reached. Generally the plant shows no obvious signs of requiring additional water for from five days to a week after growth has stopped.

5. Under certain conditions of high temperature, low relative humidity, and high wind velocity, plants may exhibit all the signs of wilt and inhibited growth that normally result from inadequate soil moisture. Such cases of temporary wilt are due to the rate of transpiration or water withdrawal being greater than the power of the roots to replenish the supply. Cane growth is resumed when the severe weather conditions are reduced.

The field studies of the Waialua project are not experimental in the sense that one treatment is compared with another. The lengths of from 10 to 20 stalks of cane are measured frequently and carefully at 19 field stations within normal commercial field areas on the plantation. The stations are located at key positions extending from one extreme of the plantation to the other and from sea level to 750 feet elevation, embracing diverse combinations of soil type, elevation, exposure and cane age. At seven stations, soil moisture samples are frequently obtained in close proximity to the measuring stations. The rate of cane growth and the rate of soil moisture depletion, with various indices of weather and environmental conditions, are plotted throughout the year.

One of the chief advantages of this type of investigation over the formal field experiment in which results are based solely on yields obtained at the end of the crop, is that it is possible to apply the information gained from cane and soil moisture measurements directly and immediately to the general field practice. Thus, it has been possible to utilize the early results, both of the Moisture Equivalent and the Cane Growth studies, in the actual plantation irrigation policy and practice within six months of the time the investigation started. The Moisture Equivalent

is used as a guide in determining, (1) how soon certain field areas are to be irrigated after a general rain, (2) to what general areas heavier or faster irrigation rounds should be made, and (3) to some extent, what marginal areas may be eliminated from production because of low moisture-retaining characteristics. The growth studies are already proving of value in indicating the frequency of irrigation necessary on certain soil areas at various times of the year, the proper balance between irrigated area and normal water supply, and the probable loss of growth resulting from inadequate irrigation applications.

The results of the first nine months of the investigation have shown considerable promise in the substantiation of the basic principles of soil moisture and plant growth determined experimentally. The results justify confidence in the Moisture Equivalent as a measure of the physical nature of the soil and as an indirect determinant of the upper and lower limits of available soil moisture. The conception that cane growth, for the period between irrigations, is at a constant rate unless the soil moisture is depleted below the Wilting Percentage of the soil has been substantiated; as has the belief that the Wilting Percentage is a function of the soil type and does not vary with increasing age of cane or with different seasons.

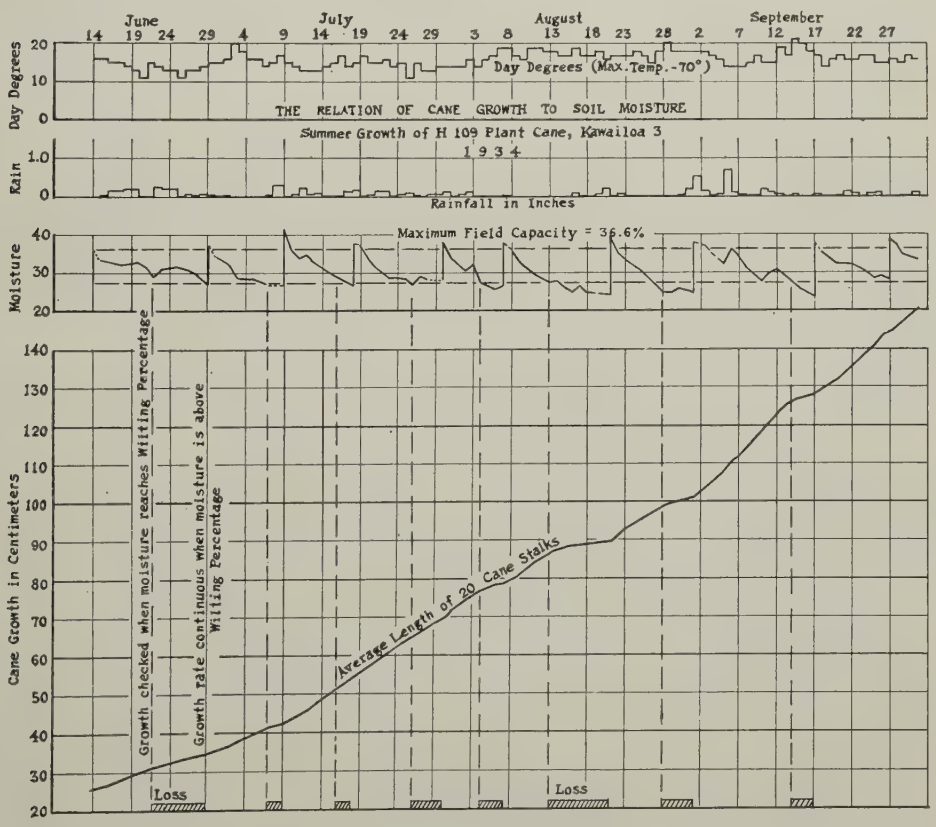

Fig. 2. Uninterrupted cane growth is dependent on maintaining the soil moisture above the Wilting Percentage.

TABLE I

COMPARISON OF THE WILTING PERCENTAGE OBSERVED IN THE FIELD WITH THE VALUE COMPUTED FROM THE MOISTURE EQUIVALENT OF THE SOIL

Field	Waimea 3			Kawailoa 3			Gay 7			Opaeula 13			Mill 2			Helemano 2A		
Moisture Equivalent	38.8			33.3			33.5			41.8			36.1			35.3		
Computed Wilting Pct. M. E. ÷ 1.2	32.3			27.8			27.9			34.8			30.0			29.4		
	Observed Wilting Percentages																	
1934	Date	Per Cent Soil Moisture	Interval (Days)	Date	Per Cent Soil Moisture	Interval (Days)	Date	Per Cent Soil Moisture	Interval (Days)	Date	Per Cent Soil Moisture	Interval (Days)	Date	Per Cent Soil Moisture	Interval (Days)	Date	Per Cent Soil Moisture	Interval (Days)
MAY				23	29.4	5												
JUNE	14	32.9	19	13	27.5	18												
				22	29.7	8	22	27.8	9									
JULY	3	35.3	15	7	27.0	8	12	27.8	9									
				16	28.8	7												
	20	34.3	8	26	27.0	8	20	29.2	6				28	32.4	14			
AUGUST	7	32.3	10	4	27.0	5	8	27.0	6	9	34.6	4	7	31.6	7			
				13	27.3	6												
	23	33.2	12	28	24.7	7	28	26.7	11									
SEPTEMBER				14	27.4	13	16	27.5	8	12	37.8	15						
				26	29.1	9				29	36.6	12	24	31.9	12			
OCTOBER				8	28.3	11	5	27.8	11	17	33.5	13	10	31.1	12	10	29.9	12
NOVEMBER				3	29.3	9	5	26.7	9				8	32.0	12			
							24	29.7	15									
DECEMBER				12	28.0	21	18	27.0	20							14	29.9	24
AVERAGES		33.6			27.9			27.7			35.6			31.8			29.9	
Divergence from Computed Value		+1.3			+0.1			—0.2			+0.8			+1.8			+0.5	

The type of data obtained may best be illustrated graphically by the relation between cane growth and the zone of available soil moisture, determined, indirectly from the Moisture Equivalent of the soil, in a field of plant H 109 cane during the summer of 1934 (Fig. 2). The Moisture Equivalent of this soil is 33.3 per cent, which gives an indirect value of 36.6 per cent for the Maximum Field Capacity and a value of 27.8 per cent for the Wilting Percentage. These limiting values are plotted as horizontal lines in the upper center of the graph. Total soil moisture percentages are plotted against the dates on which they were obtained during the summer. It may be seen that the rise of soil moisture due to irrigation, shown as a vertical line on the moisture chart, on only one occasion (when rainfall added free water to the soil at the time of sampling) reached a value more than two per cent greater than the computed Maximum Field Capacity, and repeatedly rose only to the predicted limit and no higher.

The lower curve shows the successive lengths of 20 stalks of cane as they were measured throughout the summer. It may be demonstrated by holding a straightedge against any period of growth that the rate of growth is continuous as long as the soil moisture is above the Wilting Percentage. The point at which the continuous rate of growth is checked, shown as a vertical dotted line connecting the growth curve and moisture curve, is obviously the point at which the soil moisture is reduced to the predicted value of the Wilting Percentage. The curves also demonstrate that growth is resumed at a normal rate as soon as additional water is added to the soil.

Table I compares the observed Wilting Percentage at six field stations with the computed Wilting Percentage as obtained indirectly from the Moisture Equivalent of the soil. The average values for all observations made in each field are within two per cent of the predicted value, and at four of the six stations the divergence is well under one per cent.

Summary

1. The plan and early results of a cooperative irrigation investigation undertaken by the Waialua Agricultural Company and the Experiment Station of the H.S.P.A. are contained in this progress report.

2. The investigation is divided into three phases: (a) measurement and gross distribution of irrigation waters, (b) a survey of the moisture-holding properties of the plantation soils, and (c) field studies on the relation of soil moisture to cane growth.

3. The survey of plantation soils is based on the Moisture Equivalent, a physical constant of the soil which may be readily obtained. On the basis of results from this survey, the plantation soils have been divided into five groups, each of which has definite characteristics of moisture retention and physical structure.

4. The field studies on the relation of soil moisture to cane growth are the application to commercial field areas of eight years of experimental research by the Experiment Station. The basic principles established in the laboratory, greenhouse, and field experiments have been satisfactorily substantiated during the nine months in which the field studies have been conducted.

5. Evidence from the field work is offered to show that a given soil type will hold only a definite amount of water, that cane growth is at an essentially constant rate after irrigation until the soil moisture has been depleted to a critical and constant value called the Wilting Percentage, after which normal cane growth is not resumed until additional water is added to the soil.

6. Data are presented to show that the limiting values of this zone of available soil moisture may be indirectly determined with considerable precision from the Moisture Equivalent of the soil.

7. The project is proving to be sound in principle, simple and inexpensive in design and operation, and is bringing immediate returns on the investment.

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Studies on Growth of Sugar Cane in Nutrient Solutions

By J. P. Martin

The growth response of plants to various chemical treatments is often studied under greenhouse conditions in either sand or water cultures. By using chemically pure salts and distilled water it is possible to grow plants in different media of known chemical composition and observe the effect of a special treatment upon their growth.

The sugar cane plant, like many other plants, has been successfully grown in nutrient solutions which contain the elements essential for normal development. By altering the nutrient solution, definite effects are induced in the cane plant and by this procedure, the deficiency symptoms of nitrogen, potassium, phosphorus, calcium, etc., may be studied by omitting that particular element from the basic nutrient solution. Various staff members of this Experiment Station have demonstrated by the use of sand and/or water cultures, that in certain instances an abnormal development of the cane plant in the field is caused by a faulty nutritional soil condition, e. g., Pahala blight which is caused by a manganese deficiency.

The object of this paper is to record some of the nutritional studies of the cane plant that have been carried out in water and sand cultures during the past two years. The results of each experiment recorded herein have been given briefly in the Director's Monthly Report but in most cases without illustrations. In these experiments, two different nutrient solutions were used and will be referred to from time to time as nutrient solution "A" or "B." The partial volume molecular concentrations per liter of the chemically pure salts in each solution follow:

	Solution "A"	Solution "B"
$Ca(NO_3)_2.4\,H_2O$	.009	.003
$Ca\,Cl_2.2\,H_2O$	....	.004
KH_2PO_4	.0045	.001
$K\,NO_3$	....	.003
$Mg\,SO_4.7\,H_2O$	.0045	.001
$H_3\,BO_3$	.00002	.00002
$Na_2SiO_3.9\,H_2O$	.00001	.00001

In each solution, iron was added at the rate of 10 parts per million (p.p.m.) from ferrous ammonium sulphate, while manganese was supplied at the rate of .25 p.p.m. from manganous sulphate.

Experiment 1

The Effect of the pH Value of the Nutrient Solution on Sugar Cane Growth:

Favorable cane growth has been obtained in "complete" nutrient solutions which have been prepared with distilled water. The cost of distilling water becomes an important factor to consider when large volumes are used. For certain experimental work it is not necessary to use distilled water for the preparation of

Fig. 1. Showing cane growth in nutrient solution "A" prepared with tap water (containers A and B), boiled tap water (containers C and D) and distilled water (containers E and F). Note growth failure of plants in solutions prepared with tap water and boiled water (A, B, C, D). Normal growth resulted with solutions prepared with distilled water (E and F).

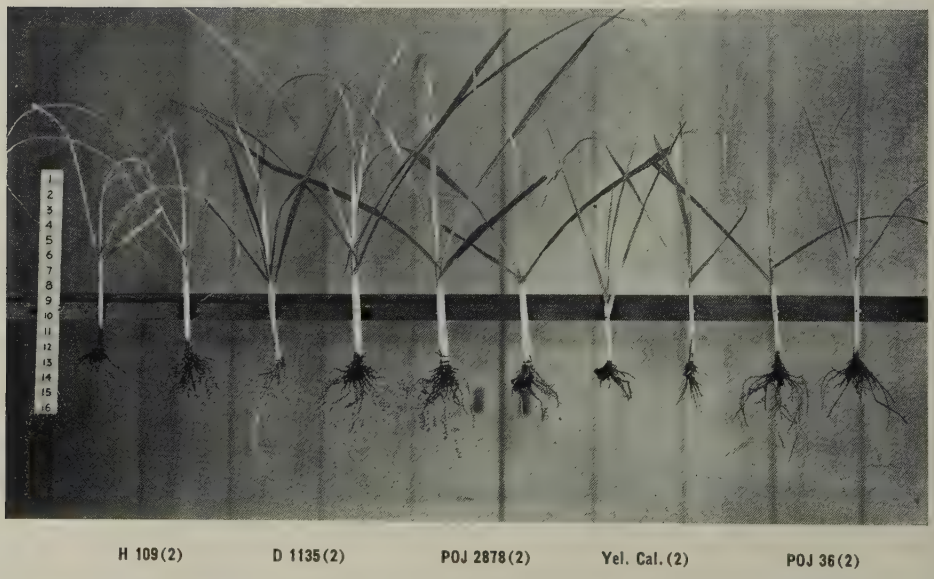

Fig. 2. Showing growth failure of plants in nutrient solution "A" prepared with tap water. Age of plants, 73 days. The plants failed to grow and many died; the root systems were poorly developed, short and stubby, and badly affected with root rot disease.

Fig. 3. The plants in nutrient solution "A" prepared with boiled tap water failed in a manner similar to those shown in Fig. 2. Note the dead and chlorotic tops on several varieties and the poorly developed root systems on all plants. These symptoms are similar to those of iron deficiency.

Fig. 4. Showing the contrast of plant growth in nutrient solution "A" prepared with distilled water and boiled tap water. The roots which developed in the latter were severely injured with root rot, badly discolored and manifested an iron deficiency type of growth which is characterized by short, stubby roots. The plants in the same nutrient solution prepared with distilled water produced a normal growth.

the nutrient solutions. In this experiment, studies were made of cane growth in nutrient solutions prepared with tap water and distilled water.

In these studies, shoots from germinated cuttings of the following varieties were used: H 109, POJ 2878, Yellow Caledonia, D 1135, POJ 36 and Lahaina. One plant of each of the first four varieties and one of either POJ 36 or Lahaina were placed in a five-gallon earthenware jar and held in an upright position by placing two halves of a large cork around each plant and then fitting the cork and the plant as a unit tightly into a circular hole in a wooden cover (Fig. 1).

The purpose of placing five varieties in a single pot was to have each variety receive identical treatment. With this arrangement, any differences that developed in a single treatment might readily be interpreted as varietal response rather than as some conditional factor. This method has certain advantages over the method where each plant is grown in an individual container.

Shortly after the plants were placed in nutrient solution "A" prepared with tap water, the leaves began to manifest definite symptoms of iron deficiency. Later, the leaves showed acute iron deficiency symptoms; the roots developed a distorted or "stubby" type of growth, also characteristic of iron deficiency; and many of the roots were badly rotted by the fungus *Pythium graminicolum*. At the end of 6 weeks the majority of the plants either exhibited a total growth failure or were dead.

Prior to the death of the plants, almost every root had become soft or flaccid as a result of root rot. In order to determine the relation of *Pythium* root rot to the growth failure of the plants, another angle to this experiment was designed, after discussing the problem with C. W. Carpenter, wherein tap water, boiled tap water, and distilled water would be used for preparing the nutrient solutions. It was thought that the *Pythium* fungus might be present in sufficient quantities in tap water to cause an acute rotting of the roots. In view of this possibility, tap water in one series was to be boiled before using so that the *Pythium* factor might be eliminated.

In this phase of the work, two five-gallon containers with a similar arrangement of plants were used in each of the three treatments. The leaves of the plants in the nutrient solutions prepared with tap water and boiled tap water soon began to show symptoms of chlorosis. The growth of the plants was greatly retarded and the root development was extremely weak (Figs. 1, 2, 3 and 4). The majority of the plants were dead at the end of from 6 to 8 weeks, and the growth failure of the plants agreed in every respect to that previously described.

The cane plants in the nutrient solution prepared with distilled water produced a normal growth and the roots were exceptionally healthy (Fig. 5).

The nutrient solutions prepared with distilled water were found to be more acid than those prepared with tap water, the former having a pH value of 5.0 to 5.2, and the latter, a pH value of 5.8 to 6.0. Since the plants in the tap-water solutions manifested definite symptoms of iron deficiency, it was thought that due to the alkalinity of the solution, the iron was changed to insoluble ferric hydroxide and the failure of the plants was caused by an iron deficiency.

In further studies cane plants were grown in nutrient solution "A," which was prepared with tap water and adjusted to a pH value of 5.0 to 5.2 by the addition

Fig. 5. Showing the normal growth of plants in nutrient solution "A" prepared with distilled water. The pH value of the solution was 5.0 to 5.2, whereas that prepared with tap water or boiled tap water was 5.8 to 6.0. Note the healthy top growth and root development of the plants in contrast to those in Figs. 2 and 3.

Fig. 6. The large plants were grown in nutrient solution "A" prepared with tap water and adjusted to a pH value of 5.0 by adding sulphuric acid. The small plants were grown in a similar nutrient solution which was not acidified; these plants manifested acute iron deficiency symptoms before they died.

of sulphuric acid, and in a similar solution which was not adjusted or acidified. In the acidified tap water cultures the plants made a normal growth, whereas in the unadjusted tap water solutions the plants again failed in a manner similar to that already described. The marked differences between the adjusted and unadjusted tap water cultures on cane growth are shown in Fig. 6.

The results of these experiments demonstrate that the pH value of the nutrient solution should be approximately 5.0 to 5.2 in order to maintain the iron in a form which is available to cane plants, and if tap water is used for preparing the nutrient solutions it is necessary to adjust the pH value accordingly.

The pH value of ordinary tap water at the Experiment Station when these tests were being conducted was found to be 7.8 to 8.0 while that of distilled water was from 6.8 to 7.0. The addition of the chemicals to the distilled water in preparing the nutrient solutions raised the acidity or changed the pH value from 7.0 to between 5.0 and 5.2 which proved favorable for cane growth. However, when the same chemicals were added to tap water, the solution became more acid but only to the pH value of 5.8 to 6.0 which proved unsatisfactory for normal cane growth; when the pH value was adjusted to 5.0 or 5.2 by the addition of sulphuric acid, the iron at this acidity was in the form of ferrous sulphate which is soluble and readily available to the plants.

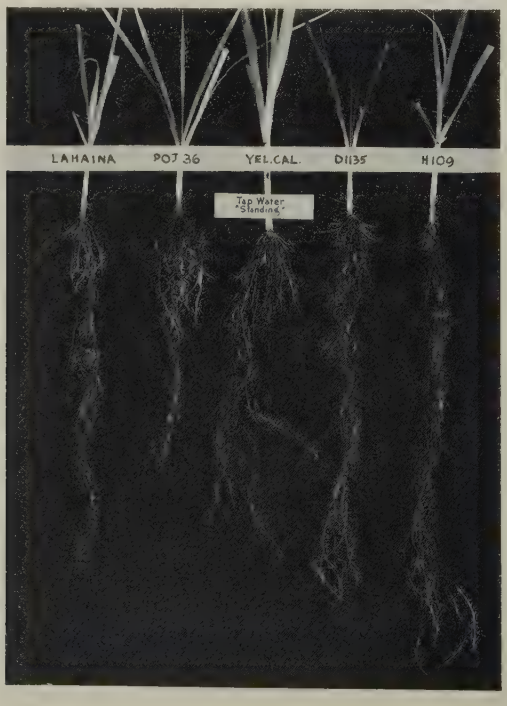

Fig. 7. Sugar cane plants at the age of 3 months that have been grown entirely in tap water. The plants made a slight top growth and only a moderate root development during this period. The leaves were at all times chlorotic.

Experiment 2

Cane Growth in "Standing" Tap Water, "Running" Tap Water and in Distilled Water:

Since water is the most essential element for sugar cane development, it was considered desirable to study the type of cane growth produced from young shoots when grown in tap water and in distilled water.

Young shoots of a uniform size were selected from germinated cuttings of the varieties Lahaina, POJ 36, Yellow Caledonia, D 1135 and H 109. One shoot of each variety was placed in a five-gallon earthenware jar and held in an upright position similar to the method described in Experiment 1. In the following experiment no nutrients other than those in the water itself were supplied to the plants.

The cane plants in each of two containers received the following treatments:

A. Standing tap water—where ordinary tap water was supplied to the plants and changed once a week.

B. Running tap water—where a constant supply of tap water was supplied at the bottom of each container and allowed to overflow near the surface of the jar. In this test the plants were at all times in contact with slowly circulating tap water.

C. Distilled water—where distilled water was supplied to the plants and changed once a week.

The plants in the standing tap water treatment failed to make any appreciable growth during the experiment. The leaves were of a light greenish color which suggested nitrogen deficiency. The roots of each variety made a fair development in comparison to the top growth; however, they were small in diameter and lacked vigor but were comparatively free from disease. The top growth and root development of each variety are shown in Fig. 7. The pH value of the tap water was 7.7 to 8.0 but after it had remained in contact with the plants for one week it was found to be 6.8. The reduction in pH may be explained by the release of carbon dioxide (CO_2) by the roots.

In the running tap water the plants manifested a slightly better growth than those in the standing tap water, possibly due to the constant supply of water which contained small amounts of plant nutrients. The leaves exhibited rather definite symptoms of iron deficiency. The roots were greatly depressed in growth, small in diameter and moderately affected with root rot. The roots were also stubby in growth which is one characteristic of iron deficiency. The growth of the plants at the end of the experiment is shown in Fig. 8. The pH value of the water was approximately 8.0, and since a continuous flow of water was supplied to the plants at all times the pH value remained unchanged.

In the distilled water treatment the plants made no top growth whatsoever and the leaves were chlorotic in appearance, but such results would be expected from a medium lacking nutrients. The root development indicated that the plants possibly obtained small quantities of nutrients from the water itself but more probably they utilized the nutrients which they held in reserve at the beginning of the experiment. The roots were small in diameter, somewhat stubby in growth and

Fig. 8. Young sugar cane plants failed to make any appreciable growth in tap water which was slowly flowing at all times. The top development of the plants was similar to that shown in Fig. 7, but the root systems were very much less and assumed a short, stubby type of growth. Age of plants, 3 months.

Fig. 9. When young cane plants were placed in distilled water they failed to make any further top growth but did develop fair root systems. Age of plants, 3 months.

free from disease. The volume of roots was slightly greater than in the other two treatments. The development of the plants in distilled water is shown in Fig. 9.

The above test was repeated with similar results. From these experiments it is evident that young cane plants are unable to make any perceptible growth in tap water or in distilled water alone.

Experiment 3

Cane Growth in Relation to Acidity:

At the suggestion of H. P. Agee, an experiment was conducted in water cultures for the purpose of studying the growth of the sugar cane plant in culture solutions of different pH values or different acidities.

Young plants which were obtained from germinated cuttings of H 109 and POJ 2878 were grown for five weeks in nutrient solution "B." During this period all plants made a very uniform growth. The pH value of the solution was from 5.0 to 5.2, i.e., slightly acid.

On November 7, 1933, plants of a uniform size were transferred to complete nutrient solutions the pH values of which were adjusted to 2.0, 3.0, 4.0 and 5.0 respectively by the addition of sulphuric acid. Sufficient sulphuric acid to maintain the desired pH value was added daily to each series.

The solution having a pH value of 2.0 proved toxic to plant growth. The plants made no further growth; the leaves developed a yellowish color, and the roots became flaccid and badly discolored. At the end of five weeks the plants were dead.

At pH 3.0 cane growth was greatly retarded. The majority of the roots became flaccid and discolored. The tips of the older leaves died prematurely and the blades were marked by alternating brownish and green stripes. In further studies this particular striping has been definitely associated with acid injury. The plants, however, remained alive but made no appreciable growth at this acidity.

The plants in the solution maintained at pH 4.0 continued to make a good growth throughout the test and no leaf symptoms of acid injury appeared.

In the medium which was adjusted and maintained at a pH value of 5.0, the plants produced the maximum growth and at all times appeared to be exceptionally healthy.

This experiment was started November 7, 1933 and was completed January 12, 1934. The growth response at the four different acidities is shown in Fig. 10. The higher acidities, namely pH values of 2.0 and 3.0, proved detrimental to the development of the plants, whereas the plants made a normal development in the solutions which were less acid.

Experiment 4

The Effect of Varying Amounts of Manganese on the Growth of Sugar Cane:

Pahala blight of sugar cane, which is caused by a manganese deficiency in the plant, is recognized by the presence of alternating dark green and narrower chlorotic-to-white stripes on the leaves. Definite symptoms of Pahala blight may readily

Fig. 10. Showing the effect of varying degrees of acidity on sugar cane growth. At pH 2.0, the plants soon died; at pH 3.0, growth was greatly retarded; at pH 4.0, fairly good growth resulted, while at pH 5.0, normal growth was obtained.

be produced by growing cane plants in a manganese-free nutrient solution. It has been demonstrated that an extremely small quantity of manganese is essential for normal cane growth.

Since the lack of manganese has a very definite detrimental effect on the cane plant, it occurred to the writer that it would be interesting to determine the effect of high amounts of manganese on the development of sugar cane.

In these studies H 109 cane plants were grown in nutrient solution "B" for a period of five months. Iron was added to the nutrient solution at the rate of 10 parts per million (p.p.m.) from ferrous sulphate, while manganese was supplied from manganous sulphate at the rate of .25 p.p.m. The plants at the end of this period were 6 to 7 feet in height and growth appeared normal in every respect.

On September 18, 1934, plants of a uniform size were placed in nutrient solutions wherein manganese was added at the rate of .25, 10, 20, 40 and 80 p.p.m. respectively. At the end of four weeks a pale striping similar to the early symptoms of iron deficiency appeared on the young leaves of the plants receiving 20, 40 and 80 p.p.m. of manganese. The striping was most conspicuous on the plants in the higher concentrations of manganese.

At the end of the fifth week the alternating dark green and chlorotic stripes were very definite on all plants which were receiving 10, 20, 40 and 80 p.p.m. of manganese. Within 8 weeks the young leaves were uniformly chlorotic and the plants receiving the three higher concentrations of manganese were depressed in growth (Fig. 11). The plants receiving .25 p.p.m. of manganese developed nor-

mally, and the roots were exceptionally healthy and vigorous. The roots on the other plants were badly discolored and rotted (Fig. 12).

The chlorotic condition of the plants which developed only at the four higher concentrations of manganese was in every respect similar to iron deficiency. It is very likely that the iron in the nutrient solution was oxidized to ferric oxide in the presence of the high amounts of manganese, and since ferric oxide is insoluble, the plants were unable to obtain sufficient iron for their normal development. This explanation is offered merely as a tentative theory and further studies are to be conducted in order to check this hypothesis. The cause of ratoon chlorosis in sugar cane, especially on the red soils which are known to have a high iron content, may be due to a temporary tying up of the iron in the presence of high amounts of manganese in the soil.

Experiment 5

Sugar Cane Growth in Aerated vs. Non-Aerated Water Cultures:

Plant growth in nutrient solutions is greatly improved when air is slowly bubbled through the solutions. In the writer's experience with sugar cane plants grown in nutrient solutions, excellent growth has been the rule for three or four months; following this period the roots gradually become discolored and show evidence of root rot. The deterioration of the root systems is comparatively slow at first but in time the roots are often severely injured. The severity of the injury usually varies directly with the variety grown, since certain varieties are more resistant than others to root rot disease.

In order to study the effect of aerating water cultures on cane growth, the following experiment was conducted. Ten five-liter percolator jars were held in an upright position by a specially constructed stand as shown in Figs. 13 and 14. All jars were filled with nutrient solution "B." Air supplied from a pressure tank was permitted to bubble slowly through the first five jars (Fig. 14). The flow of air entering the bottom of each jar was regulated by a glass stopcock. In this test young shoots of a uniform size from germinated cuttings of POJ 2878 and H 109 were used. Shoots of POJ 2878 were placed in the first two jars of the aerated and non-aerated series, while H 109 shoots were placed in the three remaining jars of each series. The young plants were held in wooden covers with the aid of large corks (Fig. 14). Each jar was covered with heavy black roofing paper in order to exclude light.

From the very start of the test the plants in the aerated cultures showed the better development. Within a month the roots of both varieties in the aerated cultures were considerably longer than those in the unaerated cultures. The solutions were changed once a week and toward the latter part of the experiment, additional solution was added to the jars in order to maintain a more constant volume of liquid so that the upper roots would not become dry. At the end of three months a marked difference was apparent between the top growth and root development of the plants in the two treatments. This difference became more marked as the experiment was continued. After seven months the experiment was terminated, the differences being shown in Figs. 13, 14 and 15.

Fig. 11. H 109 cane plants A, B, C, D and E were grown in nutrient solution "B" to which were added respectively, .25, 10, 20, 40 and 80 parts per million of manganese. Normal growth resulted in the solution which received .25 p.p.m. The plants in the other four treatments manifested definite symptoms of iron chlorosis which increased in severity with increased amounts of manganese.

Fig. 12. The root systems of H 109 cane plants shown in Fig. 11. Note healthy appearance of root system A in contrast to the others which are badly discolored and affected with root rot disease.

In the aerated cultures the diameter of the stalks and the height and color of the plants were superior to those in the non-aerated solutions (Figs. 13 and 14). A marked difference in root development between the two treatments (Figs. 14 and 15) appeared to be very significant. The roots in the aerated cultures remained healthy and showed only traces of root rot, while the roots in the non-aerated solutions were severely affected with root rot as shown in the photographs. In the non-aerated solutions the roots of the POJ 2878 plants made a better growth than those of the H 109 plants and were less injured by root rot.

This experiment shows that a much superior growth in every respect was obtained in the aerated solutions. Subsequent tests have also shown that other varieties produce a much better growth in nutrient solutions which are aerated. The fact that the amount of root rot was so markedly reduced in the aerated cultures makes the method extremely valuable since root rot in water cultures is often the limiting factor for growth. It is impossible to study the effects of a particular treatment on the cane plant when root rot is severe.

Experiment 6

Growth of Lahaina in Aerated Water Cultures:

Young shoots from germinated cuttings of Lahaina were placed in one-gallon earthenware containers which were filled with nutrient solution "B." These solutions were aerated during the growth of the plants by allowing air under low pressure to enter the bottom of the container and slowly bubble through the solu-

Fig. 13. All plants received nutrient solution "B." The solutions in which the first five plants were grown were aerated, while those in the remaining five containers were not aerated. Note the superior top growth and root development of the plants grown in the aerated solution.

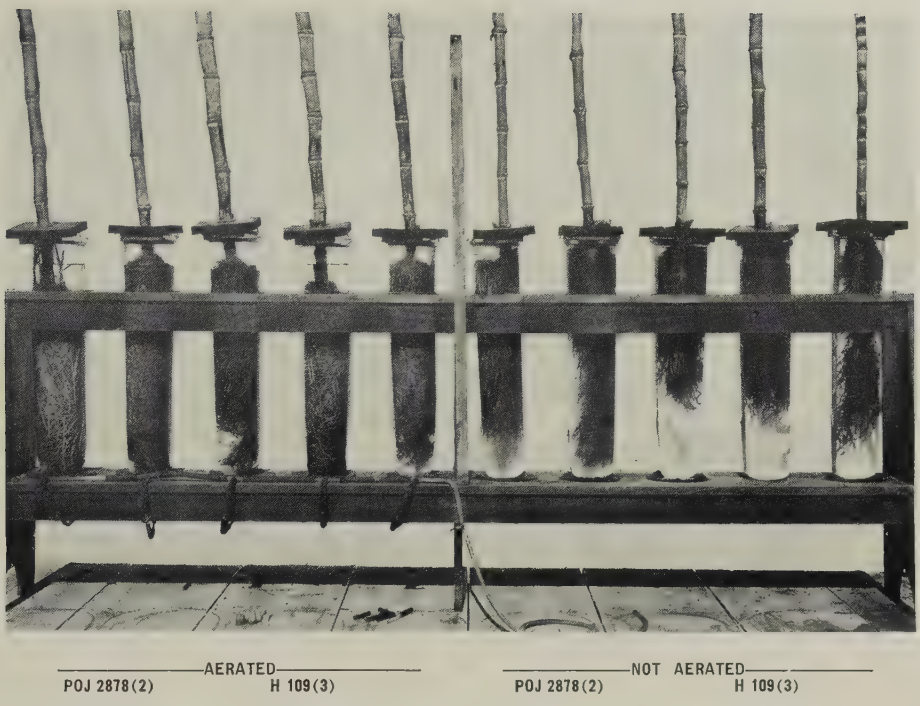

Fig. 14. The stalks of the plants in the aerated culture solutions were the larger. The root systems were exceptionally free from root rot in contrast to the severely injured root systems in the non-aerated solutions.

Fig. 15. Showing the root systems of the plants which were grown in aerated and non-aerated culture solutions, after being removed from the glass percolator jars.

Fig. 16. Lahaina plants grown in nutrient solution "B" which was aerated. At the age of 10 months these plants were 12 to 14 feet in height and 1½ to 2½ inches in diameter. This growth was produced in one-gallon earthenware jars.

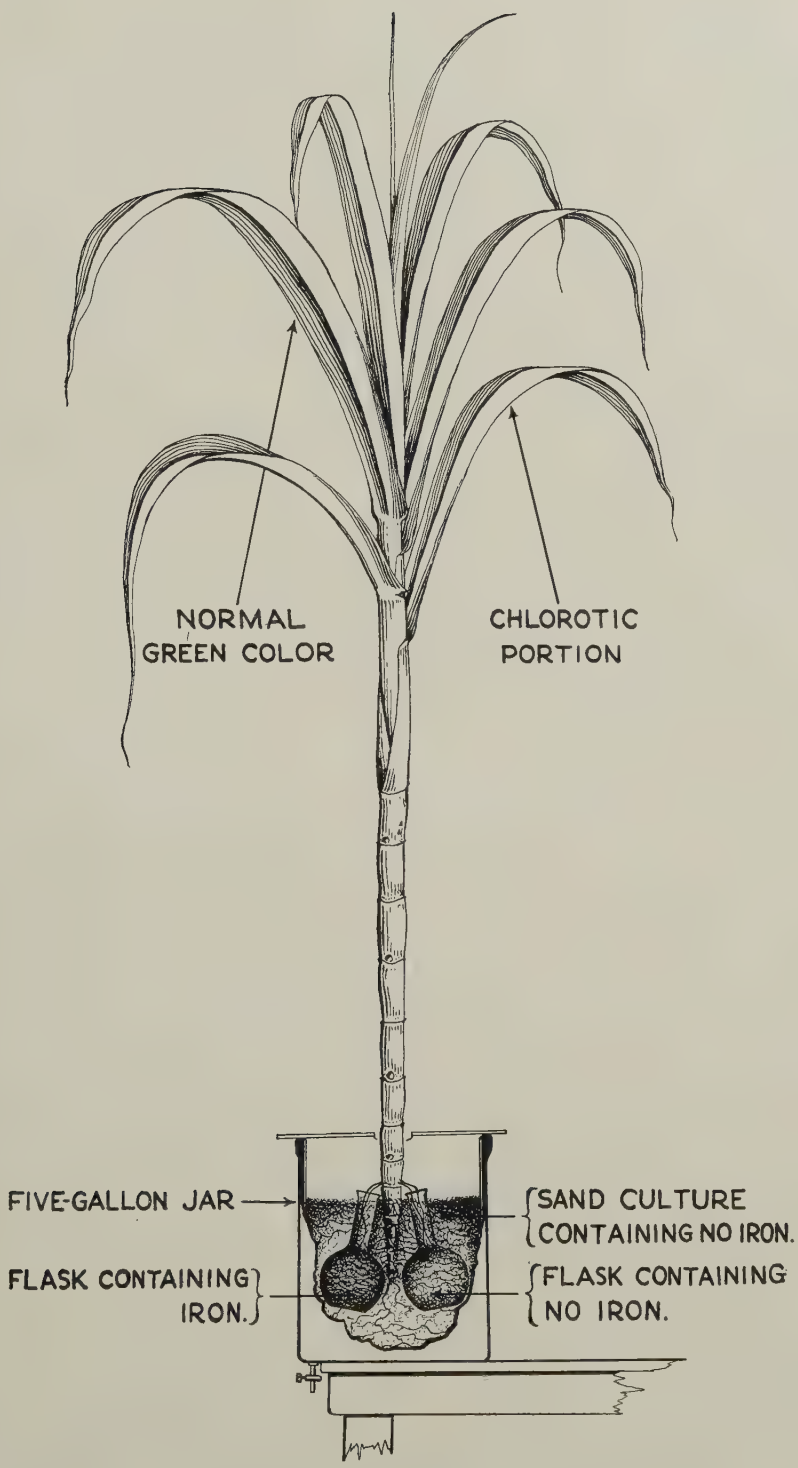

Fig. 17. When a chlorotic H 109 cane plant was supplied with iron through two roots, the normal green color developed only on the half of each leaf on the side supplied with iron.

tion. The flow of air into each jar was regulated by a glass stopcock; the amount of air being bubbled through the solution in each jar was observed by having the air bubble through an auxiliary container or flask before entering the opaque plant container (Fig. 16).

The plants made a normal growth at all times and at the end of ten months were from 12 to 14 feet in height with a stalk diameter varying from 1½ to 2½ inches (Fig. 16). This test demonstrates the excellent cane growth that may be obtained in small containers, and also shows that aeration of water cultures has desirable features. The plants in this test are the largest ones grown to date by the writer and they were still alive and growing three months after the photograph, Fig. 16, was taken.

Experiment 7

Supplying Iron to the Cane Plant Through Two Roots:

On January 10, 1934, iron was withheld from two H 109 cane plants, five feet in height, which had been growing in sand irrigated with nutrient solution "B." Very definite symptoms of iron deficiency soon appeared on the young leaves. In the meantime roots were induced to develop from a node slightly above the surface of the sand by keeping this region of the plant moist.

The leaves of the cane plant are borne in two ranks on opposite sides of the stalk, lying approximately in the same plane. Two roots developing on one side of the plant and at right angles to the plane of the leaves were directed into a 500 cc. flask which at the beginning of the experiment had been buried in the sand. Two other roots from the same node but on the opposite side of the plant were treated in a similar manner. Each flask was placed so that its mouth was one inch above the surface of the sand thus preventing the solutions within the flasks from coming in contact with the sand culture. The side roots detoured into the flasks were grown in an iron-free solution. The arrangement of this test is shown in Fig. 17.

By March 10, 1934, the plants manifested very definite symptoms of iron deficiency, the young leaves being uniformly chlorotic. On this date iron at the rate of 10 parts per million was added to the nutrient solution in one flask in order to learn whether or not as few as two roots could take up sufficient iron for the normal growth of the entire plant. Within 5 days a partial greening of the chlorotic leaves was apparent. This greening was not over the entire leaf as might have been expected but appeared only on the halves of the leaves on the side of the plant from which developed the two roots receiving iron. At the end of 14 days the half of each leaf on the side supplied with iron was of a normal green color from the base to the tip, while the portion on the other side of the midrib remained chlorotic. The contrast between the normal and the chlorotic half of each leaf was very striking (Fig. 17).

The above experiment was repeated and similar results were obtained. From these tests, which demonstrate that individual roots may supply specific regions of the plant with nutrients, several interesting theories have been advanced regarding the uptake and distribution of nutrients within the plant. The supply of plant nutrients through individual roots and its significance or application to field practice has been a subject for discussion.

Phosphate Fixation in Hawaiian Soils—IV
Rapid Methods for Determining Capacity, Rate, Degree and Differentiation of Fixation

By Francis E. Hance and Q. H. Yuen

The phenomenon of phosphate fixation in soils is recognized, we believe, as having practical significance in sugar cane agriculture. When occurring in a moderate degree, fixation may be looked upon as a benefit to the farmer, for it then becomes a means of withholding the nutrient against leaching. However, when fixation is excessive and an application of water-soluble phosphate becomes so firmly held in the soil that plants may have difficulty in obtaining quantities necessary for growth and development, then phosphate starvation may be looked upon as inevitable.

It has been found to be generally true in Hawaiian soils that the capacity to absorb soluble phosphates varies in rate and degree with the individual soil. In papers by Davis (2), Ayres (1) and Hance (4) which have appeared previously in this journal, these findings are discussed in detail and relevant experimental data are offered.

The Development of the First Experiment Station Rapid Fixation Assembly:

Early in the course of our general research upon soil phosphate fixation, the Director of this Experiment Station, H. P. Agee, and the senior author of this paper undertook the development of a kit-like ensemble embracing a simple and straightforward means of evaluating phosphate fixation in any soil by employment of procedures on a miniature scale identical in scope and kind with actual field fertilizer practice. Cognizance was made of the fact that fixation occurs in the field only as a result of absorption of applied soluble phosphates by the soil in the presence of soil moisture and subject to the influences of natural phenomena. It became patent, then, that factors to be considered by the investigator for laboratory study need embrace but the simple essentials—soil, fertilizer and moisture—for under field conditions where an application of phosphate fertilizer may become "fixed," these primary materials only are involved. Furthermore, it was recognized that any ensemble or kit which might be developed for evaluating soil phosphate fixation must be simple in design and fool-proof in operation to be fully reliable and equally effective in the hands of an inexperienced as well as in those of a trained operator.

It was in September of 1932 that the first satisfactory kit was developed and put into use. After subjecting the original ensemble to careful study and critical trial, about 25 additional kits were built and stocked in our laboratories and later distributed among interested plantation workers.

The kit consisted of a case stocked with graduated bottles, funnels, filter papers, necessary reagents and a set of color standards. The bottles were of two-ounce liquid capacity, sufficient to hold 5 grams of soil and 30 cc. of fixation solution.

The reagents, other than the fixation solution, were ammonium molybdate and stannous chloride. These were employed in the test to produce the characteristic blue coloration indicative of phosphate concentration in the leachate following the fixation of applied phosphate in the soil under study. One pint of fixation solution comprised the reagent of greatest bulk. It consisted of a phosphate fertilizer dissolved in distilled water and adjusted to a concentration equal to 100 parts per million of phosphate calculated as P_2O_5. The principles involved in the determination are discussed later in more detail.

In general, laboratory tests for phosphate fixation follow the principle of adding a definite amount of the nutrient to a soil the phosphate concentration of which is known, and then after fixation is completed, of removing the phosphate remaining unfixed. The soil is then analyzed for phosphate. The final concentration in the soil minus the initial concentration will represent the amount fixed. However, in actual laboratory practice difficulties arise in the removal of unfixed phosphate which render the scheme impractical. An alternative is to determine the concentration of a solution of phosphate before and after passing it through a soil, fixation having taken place in the meantime. The difference between the initial and the final concentration of phosphate in the solution is the amount fixed by the soil. This latter method is employed in the Experiment Station rapid fixation test.

The procedure initially adopted involved the adding of a known amount of soil to a neutral phosphate solution of definite concentration. The soil was shaken with the solution and allowed to stand overnight; then the mixture was filtered. Reagents (ammonium molybdate and stannous chloride) were added to the filtrate which developed a blue color, the intensity of which was approximately proportional to the phosphate remaining in solution. By comparing the color developed in the filtrate with that of a series of standards the fixation capacity was ascertained and the results tabulated in arbitrary numerical indices ranging from 0 to 90, with step intervals of 10. The lighter the color, the greater the removal of phosphate from the solution by the fixation process and hence higher the fixation.

The limits of shade variations in the color standards used for this work were established by designating the maximum blue color developed in a 100 parts per million phosphate solution as "0" and that pale shade produced in a solution containing only a mere trace of phosphate as "90." The deep blue "0" index then, in a test would obviously indicate little or no fixation as having taken place, whereas the "90" index would indicate maximum measurable absorption of phosphate and hence would be indicative of very high fixation. The range of color shades between these two extremes, i.e., "0" and "90," was divided into eight convenient gradations. A total of ten graded shades of blue was thus made available by this arrangement. Numerical indices were assigned to these variations. Placed in convenient tubes in a rack sliding through an illuminated field, these graded colored solutions comprise the standards of reference used in the measurement of fixation indices.

It is recognized that fixation of phosphate in the soil may result in the formation of insoluble phosphates of the available form, or of a difficultly available form, or perhaps both. The phosphate may become insoluble through precipitation and yet may remain available to a greater or lesser extent. Experiments of cane feed-

ing with certain insoluble phosphates have been successfully conducted by members of the staff and later reported by Hance (4). In addition to this form of fixation, another may take place in which a larger proportion of the nutrient may be tenaciously withheld from utilization by the plants. Fixation of this latter type has been reported by Davis (loc. cit.). The usual laboratory methods of determining availability of phosphate in the soil have involved extractions with dilute acids. Solutions of phosphate in acid media are generally used in the study of fixation, as exemplified by the method of Demolon and Barbier (3).

The procedure used in the rapid kit method does not entirely ignore approved laboratory convention, except insofar as the fixation is brought about in a non-acid treatment and only in the presence of water, soil and a phosphate fertilizer. Rather than attempting to differentiate between the two forms of fixation mentioned above, the kit ensemble was designed to measure the fixation capacity of the soil by duplicating on a miniature scale the operations involved in field practice. The treatment of a soil with a neutral solution of phosphate may be considered as comparable in general to the application of fertilizer followed by irrigation. This method of employing a neutral fixation solution tends to maintain natural conditions of acidity or alkalinity in the soil as it may have existed before a phosphate fertilizer was introduced. Little or no re-solution of phosphate, already present in the soil, should occur in such a treatment and as a consequence the initial concentration of the fixing solution may be considered as practically unaltered, thereby contributing to the simplicity of the operation. Complications due to solubility effects or to other altered soil condition through the use of an acid treatment are at the same time avoided.

Relationships Between Fertility and Fixation:

Experiences of agriculturists have indicated that for Hawaiian soils, fertility with respect to phosphate fixation appears to be associated in most cases with the degree of fixation. Data obtained by the rapid kit method of analysis appear to be particularly applicable to such a consideration. From his researches on the mechanism of fixation, Davis (loc. cit.) has found that for many Hawaiian soils, the theory of fixation by precipitation with calcium, magnesium, iron, aluminum and titanium does not account for all of the fixation which may take place. Davis advances the theory of absorption to account for the maximum fixation occurring in upland Hawaiian lateritic soils. Ayres (loc. cit.), using refined laboratory procedure, has obtained results which lead, with certain exceptions, to conclusions similar to those enumerated above regarding the association of soil fertility with phosphate fixation. He found, however, that the matter of fertility did not correlate with propensity of fixation for some soils of the island of Hawaii. High fixation, as determined by present laboratory methods in certain exceptional soils, was not found as being correlated directly with low productivity.

The Fixation Solution:

The fixation solution used in the rapid kit method is prepared from diammonium phosphate, adjusted to neutrality and buffered so that filtration may be fa-

cilitated. In the original test the solution had a concentration of 100 parts per million of phosphate calculated as P_2O_5. The ratio of solution to soil was adjusted so that 30 cc. of phosphate solution would be brought in contact with 5 grams of soil (equivalent to a treatment of 1,500 pounds of P_2O_5 per acre-foot, 2.5 million pounds of soil). Following the simple kit procedure as already described, soils have been analyzed in this laboratory and also by plantation workers, generally with satisfactory results. The entire range of fixation (indicated by indices 0 to 90) has been encountered in the course of the many determinations which have been made.

The Development of the New Fixation Assembly:

It was found by ourselves and plantation workers that, in the ranges from low to moderate fixation, the kit method using the 100 parts per million P_2O_5 solution gave entirely satisfactory differentiations. However, when highly fixing soils were encountered, the procedure did not furnish a sufficiently sharp differentiation of the degrees of fixation in these higher registers. The amount of phosphate used in the original kit appeared to be entirely fixed in such cases so that for extreme fixations the index of "90" became applicable to all these determinations thereby creating an apparent similarity of degree of high fixation in a great number of soils which were suspected of being widely divergent in fixation capacity. A means of refining the kit operations in respect to differentiation was given additional study by Mr. Agee and the senior author. It was recognized that differentiation of fixation in any given series of soils should be rendered easy of recognition by the investigator in *all* the ranges of fixation which may be encountered in plantation field study. A modification of procedure was planned based entirely upon the principles involved in designing the original kit. An adjunct to the kit was developed which would in no measure occasion any deviation in procedure from the standard manner already in use for determining fixation and recording the findings. The modification consisted essentially of the employment of supplementary soil treatments in which an extended use was made of more concentrated phosphate fixation solutions. After preliminary trials, additional solutions containing 500 and 1000 parts per million phosphate were selected for the supplementary kit.

These solutions were prepared from the same materials as were used for the single original fixation solution (100 parts per million of phosphate as P_2O_5). The reaction (pH) was adjusted to neutrality and the solutions were buffered to insure satisfactory filtration. It has been found in some cases that in using these more concentrated solutions a pale yellow tinge may be imparted to the test solution after fixation has occurred and filtration of the test solution has been made. The coloration is due to presence of organic matter. However, the final results are not adversely affected.

Laboratory study using the new concentrated solutions gave results which met fully the requirements of the test. The same method of differentiation was employed. The color standards used for the original kit and the index system of classification employed therein continued as the medium by which new fixation data were classified and recorded.

As far as possible the test has been made a duplication of a field study in which the behavior of a soil in fixation is determined as a result of an application of soluble phosphate fertilizer. It is designed to give the field man usable information relevant to the question of what may be expected to occur in any given field were an application of phosphate to be made at the moment. In the use of the new concentrated fixation solutions (500 and 1000 parts per million of P_2O_5, respectively), and with the ratio of volume of solution to soil maintained at the original value (i. e., 30 cc. to 5 grams soil), the applications are equivalent to treatments of 7,500 and 15,000 pounds P_2O_5 per acre-foot of soil. In order to insure fullest fixation, the fixation solution is allowed to remain in contact with the soil for a longer period of time than was prescribed in the original ensemble. Solution and soil are shaken for three minutes at intervals of twenty-four hours, the total standing time being extended to forty-eight hours instead of the overnight period of about twelve to eighteen hours as was allowed in the first procedure when a more dilute solution was employed.

Method of Reporting Data:

The results obtained may be recorded by prefixing the serial number of the solution to the number of the color standard matched. The fixing solutions containing 100, 500 and 1000 parts per million phosphate have been designated, respectively, as solutions Series 100, 500 and 1000. Using the Series 100 solution, the index of fixation may be prefixed with "100," followed by the number of the color standard matched. For the Series 500 and 1000 solutions, prefixes of "500" and "1000" may be followed by a dash and the numbers of the color standards matching the color gradations developed in the test solution. The arrangement of data appearing in Table I may also be found convenient.

Using the modified kit containing the original solution (Series 100) plus the new, more concentrated fixation solutions (Series 500 and Series 1000) we present below a tabulation of data obtained in a typical soil comparison study. A scheme of recording results has been followed substantially equivalent to the one proposed above.

TABLE I.

FIXATION CAPACITIES OF SOIL MEASURED BY THE RAPID KIT METHOD OF ANALYSIS, USING SOLUTIONS SERIES 100, 500 AND 1000.

Lab. No.	Soil	Treatments equivalent to lbs. P_2O_5/acre-ft. 1500 — Fixation Indices Series 100	7500 — Series 500	15,000 — Series 1000
9103	Waipio	40	0	0
9677	Hawaii	40	10	0
9676	Hawaii	40	20	0
8952	Kauai	50	40	0
8979	Kauai	60	20	0
8975	Kauai	70	10	0
9680	Hawaii	70	10	0
9326	Kauai	70	30	0
9678	Hawaii	80	10	0
9670	Hawaii	80	20	0
9329	Kauai	80	30	0
9633	Maui	80	30	0
9327	Kauai	80	40	0
9667	Hawaii	80	40	0
9674	Hawaii	90	20	0
9331	Kauai	90	30	0
9640	Maui	90	30	0
9332	Kauai	90	40	0
9328	Kauai	90	50	0
9334	Kauai	90	50	0
9639	Maui	90	60	0
8877	Hawaii	90	60	20
8882	Hawaii	90	60	40
8965	Kauai	90	70	10
9672	Hawaii	90	70	10
9662	Hawaii	90	70	20
8941	Kauai	90	70	20
9668	Hawaii	90	70	30
632	Hawaii	90	70	30
9641	Maui	90	80	10
9665	Hawaii	90	80	30
9664	Hawaii	90	80	40
9072	Hawaii	90	80	40
9663	Hawaii	90	80	50
8887	Hawaii	90	80	50
645	Hawaii	90	80	50
8880	Hawaii	90	80	60
9635	Maui	90	90	40
8871	Hawaii	90	90	50
9669	Hawaii	90	90	50
9671	Hawaii	90	90	50

Significance of New Fixation Kit Data:

Reference to Table I will show that differences in degrees of fixation are revealed when soils are treated separately with the concentrated fixation solutions (Series 500 and 1000) in addition to the old standard solution (Series 100). Thus, soils which absorb all the phosphate from the dilute solution and manifest apparently a similar degree of fixation, will, upon treatment with the more concentrated solutions, behave differently if variations in high fixation are inherent in them. Similarly, treatments of 15,000 pounds phosphate will reveal greater differences. To illustrate, referring first to the column of Series 100 indices in Table I and then to the other columns in the table, we note six soils showing indices of 80, which, however, manifest new indices of 10 to 40 on treatment with 7,500 pounds of phosphate. In the use of concentrated solutions where the blue test color produced in the solution after fixation is darker than the color standard "0," the index reported is still to be considered as "0" with the prefix of the series number of the solution used for the analysis.

Likewise, the observation regarding variations in fixation capacities is true for the entire list of soils bearing the index of 90 in column 1. By treatment with concentrated solutions an apparently high fixing soil can easily be differentiated as high, moderately high, or extremely high in fixation. Thus, taking soils Nos. 9674, 9672 and 645 from the island of Hawaii—these three soils possess apparently identical fixation of 90 in the Series 100 group, all showing high fixation. After treatment with the concentrated solutions magnifications of differences in fixation capacities in the soils are clearly shown. Thus, for the three soils we find:

Soil	Fixation Indices			Degree of Fixation
	Series 100	Series 500	Series 1000	
9674	90	20	0	High
9672	90	70	10	Moderately high
645	90	80	50	Extremely high

A Comparison of Rapid Kit Methods of Analysis With More Detailed Laboratory Procedures:

Many of the soils included in Table I have been extensively studied in the laboratory by Davis and Ayres with more refined methods of analysis. The method of Ayres (loc. cit.) involves continuous agitation of the soil for 24 hours with a solution of phosphate which has been adjusted to slightly below neutrality. Treatments correspond to applications of 25,000 pounds of P_2O_5 per acre-foot (2.5 million pounds) of soil. Following this procedure, 50 grams of soil are treated with 500 cc. of phosphate solution containing 1,000 parts per million P_2O_5. At the end of the maceration period, the liquid is filtered and the amount of phosphate remaining in the solution is determined by a volumetric procedure which involves precipitating the phosphate as ammonium phosphomolybdate and treating the washed precipitate with standard alkali and acid. Where only a small amount of phosphate is left unfixed, the filtrate is tested by a colorimetric method comparable to the one used in the rapid kit procedure. The results are reported in per cent of P_2O_5 fixed. A comparison of the results of the studies by Davis and Ayres with soils also

analyzed by the rapid kit method is submitted in Table II. The specimens were collected from points on the island of Hawaii. Their presentation in the table follows the order approximating a route around the island, starting from Hilo, progressing through Waiakea, the volcano area, Kau, Kona and Waimea to Kohala. On the return trip to Hilo the collection began again at Honokaa, and then continued along the coastline to Wainaku. Unless otherwise stated data presented were obtained from surface soils.

TABLE II.

TABLE COMPARING THE RESULTS OBTAINED BY A LABORATORY METHOD OF DETERMINING FIXATION WITH THOSE OBTAINED BY THE RAPID KIT METHOD. RESULTS BY THE LABORATORY METHOD ARE REPORTED IN TERMS OF PER CENT P_2O_5 FIXED AFTER APPLICATION OF 25,000 POUNDS P_2O_5/ACRE-FOOT. RESULTS BY THE FIXATION KIT TEST FOLLOW THE USUAL PRACTICE.

Lab. No.	Soil	*Detailed Lab. Det., 25,000 lbs. P_2O_5/ Acre-ft. Per cent Fixed	Rapid Kit Method Fixation Indices Series 100	Series 500	Series 1000
9682	Olaa Junction, Field, surface soil	99.0	90	80	30
9684	Road cut, 20 miles from Hilo, top soil	99.1	90	80	30
9683	Road cut, 20 miles from Hilo, subsoil	99.8	90	90	50
9685	Leihua Forest, 25 miles from Hilo	69.7	80	30	0
9687	Sulfur mound near Volcano House	71.3	70	10	0
9686	Near edge of Halemaumau	2.2	0	0	0
9689	Near Thurston Lava Tubes	52.5	70	10	0
9675	Kipuka in Bird Park, forested knoll	28.2	20	0	0
9678	Profile in Kipuka in Bird Park	56.6	80	10	0
9688	Kau Desert, near Punaluu	21.8	20	0	0
9681	Kau, near flow of 1868	66.7	60	10	0
9680	Kau, near flow of 1907	74.4	70	10	0
9674	Between Puuwaawaa and Humuula Junctions	79.5	90	20	0
9679	Kohala, near Iole	84.9	80	40	0
9670	Road cut near Niulii Mill, top soil	77.4	80	20	0
9672	Kohala to Waimea	98.6	90	70	10
9673	Kohala to Waimea	93.9	90	70	10
9669	Waimea to Honokaa	99.3	90	90	50
9671	Waimea to Honokaa	99.6	90	90	50
9856	Honokaa, mauka	99.2	90	60	20
9857	Honokaa, middle belt	98.8	90	50	0
9858	Paauhau	98.6	90	60	10
9867	Paauilo, No. 9, surface soil	99.3	90	70	30
9868	Paauilo, No. 9, subsoil	99.9	90	90	40
9869	Paauilo, No. 9, makai	99.3	90	70	20
9870	Paauilo, No. 11	94.6	90	20	0
9871	Paauilo, No. 16	91.0	90	20	0
9872	Paauilo, No. 23	99.5	90	80	30
9873	Paauilo, No. 18	98.7	90	40	10
9874	Paauilo, No. 21	96.4	90	40	0
9859	Hamakua, Sample No. 5	98.8	90	40	0
9861	Kukaiau, No. 27, surface soil	99.2	90	70	30

* Data in this column were determined by either Davis or Ayres in other investigations.

TABLE II—(Continued).

Lab. No.	Soil	*Detailed Lab. Det., 25,000 lbs. P_2O_5/ Acre-ft. Per cent Fixed	Rapid Kit Method Fixation Indices Series 100	Series 500	Series 1000
9862	Kukaiau, No. 27, subsoil	99.9	90	90	70
9863	Kukaiau, No. 19	99.2	90	60	20
9864	Kukaiau, No. 8	98.8	90	60	10
9865	Kukaiau, No. 1, surface soil	95.9	90	30	0
9866	Kukaiau, No. 1, subsoil	99.7	90	90	30
9860	Kaiwiki	95.4	90	30	0
9662	Papaaloa	98.1	90	70	20
9663	Papaaloa	99.6	90	80	50
9664	Hakalau	98.8	90	80	40
9665	Honomu	98.7	90	80	30
9666	Pepeekeo	99.2	90	80	40
9667	Onomea	75.6	80	40	0
9877	Hilo, Lot 27	99.6	90	90	60
9878	Hilo, Lot 26, subsoil	99.9	90	90	80
9879	Hilo, Field 56	97.9	90	80	30
9876	Hilo Variety Station	98.9	90	80	40
9875	Hilo	98.5	90	80	40
9668	Hilo Substation, H.S.P.A.	98.6	90	70	30

* Data in this column were determined by either Davis or Ayres in other investigations.

Discussion of Data—New Fixation Assembly:

Inspection of Table II will reveal that for the initial test, i. e., Series 100 treatment, the lower ranges of fixation show a close correlation between the kit indices and the percentages of fixation as determined by a more elaborate method of analysis. From a study of the data obtained from the separate and additional treatment of soils with concentrated solutions (Series 500 and Series 1000), it becomes apparent that for soils analyzing 0 to 50 index values, the necessity does not exist for further differentiation with the concentrated solutions. However, when the Series 100 treatment shows an index value equal to or greater than 60, recourse to analysis by the concentrated solutions is desirable, with reanalysis absolutely necessary for values of 90 or greater if a finer classification of the degrees of high fixation is desired.

Rate of Fixation:

The indices obtained by the rapid method of analysis may not only be indicative of the fixation capacity of the soil, but in a measure may allow an estimation to be made of the rapidity with which applied phosphate may be fixed.

In the study of fixation by a conventional laboratory method, it has been shown that for some Hawaiian soils, fixation proceeds at a tremendous rate during the first hour and the amount fixed gradually increases until practically constant absorption is attained at the end of the first 5 to 10 hours. Fixation at this period, however, is by no means completed.

While no claim is made that the results obtained by the rapid kit method represent fixation at equilibrium conditions, the soil treatment containing the highest amount of phosphate must certainly have provided the soil with sufficient phosphate to satisfy, in a measurable degree, its propensity to fix this nutrient, and the time of contact is long enough so that the reading is made when fixation may have attained a limit wherein increase in amount absorbed becomes but negligible. It should follow then, we believe, that the rapidity with which soil removes phosphate from a fertilizer application may be estimated if the initial treatment, i. e., Series 100 analysis, is taken not only as a measure of the fixation capacity, but also as an indication of the progress of fixation during the period of high absorption. The more concentrated solution treatments, i. e., Series 500 and Series 1000 analyses, appear to indicate the progress of fixation during the period when the rate of fixation has dropped to lower values.

In the following table the soils are grouped and placed according to their fixation indices. The arrangement is in numerically increasing order, based on the Series 1000 treatment. For soils of moderate fixation, that is, those the capacity of which is represented by the index of zero after treatments of 15,000 pounds phosphate, column 2 will show capacity, and the rapidity of fixation may be judged from column 1.

TABLE III.

SHOWING THE FIXATION INDICES BASED ON THE NUMERICALLY INCREASING ORDER OF THE SERIES 1000 STANDARDS.

Lab. No.	Soil	Fixation Indices		
		Series 100	Series 500	Series 1000
9677	Hawaii	40	10	0
8975	Kauai	70	10	0
9678	Hawaii	80	10	0
9676	Hawaii	40	20	0
8979	Kauai	60	20	0
9670	Hawaii	80	20	0
9674	Hawaii	90	20	0
9326	Kauai	70	30	0
9329	Kauai	80	30	0
9331	Kauai	90	30	0
8952	Kauai	50	40	0
9327	Kauai	80	40	0
8965	Kauai	90	70	10
9641	Maui	90	80	10
9668	Hawaii	90	70	30
9665	Hawaii	90	80	30
9664	Hawaii	90	80	40
9635	Maui	90	90	40
9663	Hawaii	90	80	50
9669	Hawaii	90	90	50

In the first three soils, column 2, the same amount of phosphate is fixed in each within the longer period of treatment, whereas in the initial treatment with 1,500 pounds of phosphate for 24 hours, during a shorter period of maceration, indices of 40, 70 and 80 were obtained. It is indicated here that while the inherent capacity of phosphate fixed by these three soils may be identical within a longer period of contact, the amount taken up during the shorter period is variant. Hence, it may be concluded that the rate of fixation in these soils differs one from the other. The third soil of this group, Soil 9678, appears to fix the largest amount of phosphate within the shorter maceration period and hence the speed of fixation must have been the most rapid in this soil. It appears, then, that not only may the fixation capacity of a soil be indicated with the fixation kit but the rapidity with which fixation proceeds may also be estimated.

Detailed Procedure for Making Determination:

By following the procedure as outlined below, the agriculturist may determine with ease and rapidity, practical and accurate degrees of fixation in soils of low fixation and also in those where fixation is high and where the need exists for more exacting differentiation.

To determine capacity, rate and degree of fixation: Five grams of soil are measured in a calibrated metal cup and transferred to a 2-ounce graduated bottle previously filled to the 30 cc. mark with Series 100 fixation solution. The mixture is shaken for one minute and then allowed to stand for 24 hours. At the end of this period it is reshaken for another minute, then the liquid and soil are separated by filtration. The filtrate is collected in a 3-dram tall vial until it has been filled to about 2/3 of its capacity. One cc. of ammonium molybdate is added and the solution is thoroughly mixed. Then one drop stannous chloride reagent is introduced. A blue coloration will be produced in the test solution if phosphate remains in the filtrate. (When ammonium molybdate is added to a solution containing phosphate, ammonium phosphomolybdate is formed. This product is reduced by stannous chloride forming a blue colored solution.) This blue solution is matched against the standards already described and the results are tabulated in numerical indices. If the index obtained by this test is 60 or above, fresh portions of the soil may be retested, using the concentrated solutions.

Two 5-gram portions of soil are transferred separately to bottles containing 30 cc. each of the concentrated solutions, Series 500 in one case and Series 1000 in the other. Soils and solutions are shaken for three minutes, allowed to stand 24 hours, reshaken for three minutes, and finally allowed to stand for another 24 hours. At the end of this 48-hour period the mixture is shaken for another three minutes and filtered. The filtrate is treated in a manner similar to that for the Series 100 solution. The numerical indices are determined and tabulated with prefixes of the series numbers of the fixation solutions.

The ammonium molybdate solution is a 5 normal sulfuric acid solution containing 1.25 grams ammonium molybdate per 100 cc. In the preparation of stannous chloride solution 25 grams $SnCl_2.2H_2O$ are dissolved in one liter of 10 per cent hydrochloric acid solution.

A Means of Soil Classification:

The rapidity and ease with which soil fixation constants may be determined with the rapid methods and the distinctively individual characteristic nature of such data renders the process an ideal one as a means of soil classification.

Conclusion

A rapid method of determining fixation of applied phosphate in a soil is described wherein agitation of the soil specimen with neutral solutions of phosphate of definite variable concentrations are employed. Data relevant to fixation are ascertained by determining the quantity of phosphate remaining in the added solution as it may stand, after a given period of time, in a clear supernatent fraction above the soil sample. Rate, capacity and degree of fixation are then estimated and expressed in numerical indices. The method appears to offer a means of correlating soil fertility with soil phosphate fixation and in addition it offers an excellent means of making a general soil classification.

Low to moderate fixation in a soil may be determined by the ensemble using solutions containing 100 parts per million of phosphate from diammonium phosphate.

In cases of moderate to high fixations additional relevant data may be obtained by further analyses of fresh portions of the soil with more concentrated solutions of the same fertilizer compound.

Where differences in extremely high fixation are to be differentiated it is necessary to use concentrated fixation solutions, the treatments of which are equivalent to fertilizer applications of 7,500 and 15,000 pounds of P_2O_5 per acre-foot, respectively.

Data accruing from these tests may be correlated quite satisfactorily with those determined by more detailed laboratory methods.

Summary

Discussion is presented relevant to the development of the Experiment Station Rapid Method of Evaluating Soil Phosphate Fixation. Principles pertaining to the manner of procedure are set forth.

A detailed description is presented of the present (new) phosphate fixation ensemble—a list of reagents, apparatus and other equipment which may be used to evaluate soils in their reaction toward absorption of applied phosphate fertilizer. Differentiation of capacity, rate and degree of fixation may be estimated from the data secured. Examples are given of the application of the method to agricultural problems.

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A Procedure for Sampling Cane Juice and Soil as Used at Pioneer Mill Company, Ltd.*

By H. J. W. Taylor

Since the year 1922, several surveys of Pioneer Mill Company's soils have been made. Using the 1 per cent citric acid soluble method of analysis, it was impracticable to take more than two or three soil samples to represent a single field, and for the majority of fields but one sample was taken. This sample may have been a composite of many borings taken throughout the field, or a sample from a smaller area taken as representative of that field. When the sampling was repeated in later years, it was not definitely done in the same manner or in the same soil area or at the same stage of the cane's growth. However, it has been possible to obtain some general correlations between these soil analyses and other experimental and analytical data accumulated from the larger areas, i. e., the "mauka," the "outside," or the "pump water" areas, etc. Far more detailed information is necessary to bring these correlations to a finer point in order to formulate a differential fertilizer practice for individual fields, or parts of fields. In this regard, the recent development of the rapid kit methods of soil analysis, and the rapidity and cheapness of operating these kits presented themselves as a means of obtaining this information.

Mr. J. T. Moir first suggested to us that advantage be taken of these soil kits by sampling the soil from each "burn" at time of harvest, at the same time loading on separate cars the cane grown on that specific soil area sampled, and thereafter obtaining the potash and phosphoric acid contents of its crusher juice. Further discussion with members of the Experiment Station staff and others resulted in a method of soil sampling being developed whereby an area of approximately 0.3 to 0.5 acre is taken to represent the surrounding 5.0 acres, and data on the following subjects accumulated from these sampling stations:

(a) Kit Analysis—K_2O and P_2O_5; also pH
(b) Juice Analysis—K_2O and P_2O_5
(c) Cane Yield
(d) Brix, Pol and Purity

Cutting:

At the outset of this routine, an attempt was made to separate the boundaries of the area to be sampled by selecting the site after burning and staking it before the cutting gang commenced. In order to take a running crusher juice sample of all the cars loaded from this area, without the necessity of switching cars in the mill yard, it was necessary to select watercourses from which the cane could be loaded upon cars in an unbroken string. In many cases, however, the track lines ran in such a

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manner that it was not possible to load all the sample cane on the same line, and it was equally difficult to estimate where the track lines would run in subsequent areas in order to correct this. Sample plots are therefore selected and flagged out after the cane has been cut, and after the track line has been installed.

In order to reduce the error of mixed cane as much as possible when selecting the sample area at this stage, all cane irrespective of location is separated at the level ditches at cutting. It has been found possible to do this without slowing the cutter to any extent, and the fact that no cane is laying in the level ditch is some help to the loader.

The error due to mixed cane is thus confined to the two outside watercourses of the four or five that are selected for each sampling station. Observations made by numerous persons at the harvesting of these areas have not found this error to be a large one.

Loading:

The ticket boy, in cooperation with the harvesting luna, is responsible for supervising the loading of the sample cane. This is not difficult, as the four yellow flags marking the corners of the sampling station are visible from a fair distance, and he can see any man loading cane inside or outside of these points without standing directly over the men all the time. The loaders themselves soon become proficient in recognizing the yellow flags as marking areas that are to be loaded separately from the adjacent cane.

Sample-cane tickets of a different color than the experiment- or crop-cane tickets are placed in the car, and as there are never, or very rarely, two cane samples taken from the same level ditch, the level ditch number marked on the ticket serves to record the location of each cane sample. The cars are also marked with the same number so that the tractor driver or locomotive engineer observing the chalk marks may exercise care in seeing that the string of cars gets to the mill yard without being separated. After the cane has passed through the mill, one of the roundhouse hands removes old chalk marks to avoid confusion later.

Flume Fields:

The method of cutting cane in flume fields is exactly the same as in track fields except that the sample station instead of being four or five watercourses on a single level ditch, is three watercourses each on two level ditches, the flume running directly through the middle and the cane being loaded from 1½ watercourses on either side of the flume. Due to the larger percentage of outside watercourses in these sample stations, the error of mixing at cutting is no doubt larger.

The chance for error in loading cane from flume fields is considerably greater also, due to the difficulty in supervision at the chute. The method of fluming is exactly the same as that used in field experiments, i. e., a break is made in the fluming operation, allowing all crop cane to get several hundred feet down the flume on its way to the chute, and then a bundle of cane tops with a split section of cane stalk containing a note with the number of the plot is placed in the flume by the gang luna. Sufficient time is given the chute men, after receiving the note and plot number to take out the partially loaded car and place an empty one in the chute before fluming

is again started. The procedure is duplicated at the conclusion of fluming the cane from each plot.

In fluming these sample areas, it is not practical to have a special attendant at each chute to insure new cars being put in at the proper time, so confidence has to be placed in the gang which is handling the chute. They may be checked upon to a certain extent by noting how many partially loaded cars there are, for it is impossible that fluming would commence from every sampling area just as an empty car had been placed under the chute, or concluded just at the moment a car had been filled.

Flume cane cars are marked in the same manner as track cars.

Juice Sampling:

At the present time, juice sampling is handled entirely by the mill laboratory men in the same manner as field experiments. The number of cars representing a sample is usually from 8 to 10, so that a good running crusher juice sample is obtained. There are usually six samples taken each day, and it requires one man two hours in the morning to make the potash and phosphoric acid analyses for these samples. He records his results on a separate sheet for each field, and when the field is finished, gives his record to the field experiment department, to be entered with the other data in their record book.

Soil Sampling:

Soil samples are taken from each sampling station immediately after loading is concluded. These are not taken with an auger, but a garden trowel or small hand pick is used. The top four or five inches of soil are scraped away from the mauka lower portion of the bank, and about two handfuls of soil are dug out and placed in a bucket. This is repeated in every fifth line approximately 10 feet in from the watercourse, in each watercourse of the selected sample area. Altogether about 20 to 25 of these unit samples are placed in the bucket and are then thoroughly mixed together, then about 1½ pounds of this mixed soil is placed in a paper bag upon which the soil number is written. This sample is the one that is used for analysis.

The soil number is entered in the sampler's book with the sampling date, and information such as field slope, rockiness, physical soil condition, proximity to straight ditches, etc., is added. The level ditch number, and the number of watercourses to the road or straight ditch or fire road are also noted, so that the exact sample spot, 10 feet from the watercourse on every fifth line, may be easily relocated.

The soil is obtained from the lower portion of the mauka bank in order to avoid undue influence of a previous application of fertilizer that may have been made on the cane row. The analysis of such a soil sample should indicate the more natural fertility of the area.

Surveying:

In order to obtain accurate areas of each sample station, to work up its cane and sugar yield, it is surveyed by our civil engineering department. The flags marking the boundaries are left in the field until after surveying, so that at the conclusion of

harvest in each field the surveyors may go in and survey all the sample areas at one time. Sufficient information is taken at that time so that the exact location of each sampling station may be traced on the field map. This will be an additional aid in relocating the stations from year to year, as we shall have to do in order to watch the fertility trends that may result from a differential fertilizer practice which may be adopted.

Accumulation of Data:

At the conclusion of each analysis and after the cane and sugar yields have been computed, the data are entered in our record book as follows:

Field..... Variety..... Section..... Elevation..... Crop.....

Sample Date	Soil No.	Area Acres	Level Ditch No.	SOIL ANALYSES					JUICE ANALYSES						Tons Cane Per Acre
				pH	Potash			Phosphate Group	K_2O Per Cent	P_2O_5 Per Cent	Brix	Pol	Pur.	Q.R.	
					Per Cent	P.P.A.F.	Group								

The K_2O and P_2O_5 groups as found are located on individual field maps by means of colors (yellow, blue, green and red) representing, respectively, a High, Medium, Doubtful and Low supply. In this way it is possible to note definite trends within the fields. (Frequently the increased P_2O_5 and K_2O concentration in areas which have received filter cake or molasses may be clearly seen by a glance at these maps.)

In some cases it has already been possible to correlate the T.C.P.A. with the P_2O_5 or K_2O content, and it is evident that many interesting and valuable data will be available at the conclusion of this work. At present, some 374 sample stations have been studied for K_2O and P_2O_5 in both soil and juice since the commencement of harvesting the 1935 crop, and at the close of the year we expect that approximately 1,061 such sample stations will have been analyzed, covering 5,307 acres of the plantation. From these it is hoped that much definite information regarding miscellaneous correlations will be available, and that when specific evidences of our soil fertility differences are found, they will be of much practical use to the plantation.

A Fertilizer Policy Developed With the Aid of Experiments*

By W. W. G. Moir

At the request of the agricultural section of the Maui sugar technologists the writer has attempted to prepare, in the rather short period of time since receiving the request, a paper on just how the fertilizer policies of Pioneer Mill Company, Ltd., have been evolved through experimentation. This plantation has harvested hundreds of tests on various points connected with fertilization alone, and most of these have been studied and summarized in the tables attached to this article. The details of the treatments and the comments on each and every experiment would be of much interest to everyone but would take too much space and time in presentation here. The writer will therefore take you through the years of work from 1919 to the present time showing how the practices have changed—mostly through results of well-replicated tests. Many of the points and methods of investigation were changed and elaborated upon as the work progressed. Results of experiments on other plantations and ideas obtained in scientific articles of all kinds were used to aid in this work and to arrive at a saner fertilization of the soils at Pioneer. The writer has been connected with this work from the start, and in the last ten years in an advisory capacity in connection with his work as Agricultural Technologist for American Factors, Limited, agents for Pioneer Mill Company. Approximately half of the experiments have been carried out under the supervision of the Experiment Station, and their aid and cooperation have been most invaluable.

A short discussion of soil differences must be given to start with. Roughly, the lands of Pioneer Mill Company can be divided into three general groups or types of soils. First, there are the red and reddish-brown soils that are rather free of rocks and have been formed by weathering in their present place. Second, there are the rocky soils made up of at least two-thirds boulders of all sizes and shapes from pebbles to those the size of a small automobile. Third, there are the alluvial flats of silt, sand and gravel deposits brought down by the streams and run off from the higher elevations. The first group is found in upper Lahaina, Wahikuli, Puukoli and Honokawai sections (the lower fields of the latter two as well). The second group is found in lower Wahikuli, Lahaina and upper Olowalu sections, while the third is to be found on the flats of Puukoli, Lahaina and Olowalu. In general, the areas of the first group are deficient in phosphates to a marked degree and in potash to a more or less degree. The second group will respond to phosphates and potash to a smaller degree, while the third group seldom responds to anything but nitrogen. Naturally, any general resumé of conditions along these lines will not cover individual fields in some of these groups, but in a very general way this classification will hold. The border fields between these groupings will naturally be found partly in one and partly in the other.

* A paper presented at a meeting of the Maui section of the Association of Hawaiian Sugar Technologists, Agricultural Division, Lahaina, Maui, March 14, 1935.

TABLE I

AVERAGE FERTILIZATION AT PIONEER*

Crop Year	1st Season N	1st Season P_2O_5	1st Season K_2O	2nd Season N	Total N	Total P_2O_5	Total K_2O	Amount and Material
1924	75	52	38	97 (1)	172.5	52	38	750 lbs. (10–7–3.75) + 625 N.S.
1925	75	52	38	97 (1)	172.5	52	38	750 lbs. (10–7–3.75) + 625 N.S.
1926	87½	87½	0	87½ (1)	175	87½	0	437½ lbs. S.A. + 437½ super + 567½ N.S.
1927	90	90	60	97 (1)	187	90	60	1000 lbs. HG (9–9–6) + 625 N.S.
1928	140	190	125	75–100(1)	215–240	190	125	625–687½ lbs. (15–10) 1000 (9–9–6) 250 S.A. + 500–750 lbs. N.S.
1929	140	236	158	87–116(2)	227–256	236	158	1750 lbs. (PMS) (2¾–13.5–9) + 437½ S.A. + 562½–750 N.S.
1930	140	236	158	97–116(2)	237–256	236	158	1750 lbs. (PMS) (2¾–13.5–9) + 437½ S.A. + 625–750 N.S.
1931	152	220	121	77–102(2)	229–254	220	121	1125 lbs. A6 (4¼–19½–10¾) + 875–1000 S. A.
1932	152	220	121	77–102(2)	229–254	220	121	1125 lbs. A6 (4¼–19½–10¾) + 875–1000 S. A.
1933	152	220	121	102(2)	254	220	121	1125 lbs. A6A (muriate mixture) + 1000 S.A.
1934	145	208	110	102(2)	247	208	110	500 lbs. A17 (9½–41½) + 250 N.K.G. + 812½ S.A.
1935	154	220	120	104(2)	258	220	120	750 lbs. A19 (6.7–29¼–16) + 1000 S.A.

* These figures are not uniform for the whole plantation but are somewhat representative of the larger share of lands in each crop year.
(1), (2)—one dose and two doses.

In Table I you will find a broad generalization of fertilizer practices followed on the plantation in the years from 1924 to the present time. Changes in plant food applications can be readily seen and will be commented upon as the article progresses.

Three general soil surveys conducted by the Experiment Station in 1922, 1926 and 1927, as well as individual analyses of experimental soils, gave the first real basis upon which to proceed.

The first survey showed in a very general way the areas very low and deficient in plant foods, and they have remained that way through later surveys, although in some areas there was an improvement from the use of phosphates and potash where the deficiency was not too great. Individual samples during the last few years show much greater improvements in these plant foods through fertilization. Experimental data show distinct gains in fertility or availability of potash and phosphate through continued heavy applications. These gains have been shown in crusher juice analyses as well as in the soil analyses.

TABLE Ia

AVERAGE OF 1 PER CENT CITRIC ACID SOIL ANALYSES—PIONEER MILL CO.

1922-32

Field Groups	No. of Analyses	pH	SiO_2	CaO	K_2O	P_2O_5	Section
30-34	(16)	6.4	.12	.16	.046	.0035	(Honokawai)
A	(4)	6.6	.10	.16	.037	.0032	(Puukoli)
B	(12)	6.5	.13	.18	.048	.0065	
C	(13)	7.2	.17	.18	.040	.0054	
D	(8)	7.9	.21	.42	.067	.0289	
E	(4)	6.3	.11	.14	.030	.0030	(Wahikuli)
F	(7)	6.2	.09	.13	.032	.0056	
G	(4)	6.1	.09	.10	.021	.0071	
H	(8)	7.0	.18	.19	.039	.0082	
I	(6)	7.2	.18	.22	.043	.0129	
LA	(18)	6.8	.14	.18	.033	.0039	(Lahaina "L")
LB	(13)	7.0	.17	.20	.030	.0060	
LC	(17)	7.8	.25	.32	.038	.0164	
LD	(3)	8.1	.26	.38	.051	.0283	
O	(16)	8.0	.27	.42	.059	.0603	
MA	(7)	6.9	.20	.28	.075	.0118	(Lahaina "M")
MB	(10)	7.3	.21	.26	.057	.0123	
MC	(7)	8.0	.26	.41	.041	.0132	
MD	(17)	7.8	.22	.46	.051	.0631	
Olowalu	(51)	7.6	.27	.54	.036	.0688	(Olowalu)

Total of 241 soil analyses.

In Table Ia are given the average figures for one per cent citric acid analyses from the years 1922 to 1932. Most of these are in 1922, 1926 and 1927. The figures are divided into groups of fields, that is, all the "A's," all the "B's," all the "C's," etc. They are again grouped into sections—Honokawai, Puukoli, Wahikuli, Lahaina and Olowalu. In each grouping by section, the higher elevation fields are given first and these are followed in turn by groups at lower and lower elevations. In the Honokawai section no distinction is made between pump and mountain water areas. In the Puukoli section up until very recently the "A" and "B" fields have had only mountain water, while the "C" and "D" have had mostly pump water. In the Wahikuli section the "E," "F" and 'G" fields have had only mountain water, while the "H" and "I" have had mostly pump water. In the Lahaina section the "LA" and "MA" fields have had mountain water only, while the others have had mostly pump water. Olowalu has had a mixture of both types of water except in a few cases and these have not been separated out in the averages. Please note in Table Ia the increase in available plant foods and pH as one comes from the higher elevations of 1,500 and 800 feet down to the areas at sea level. Also note the increase in these figures as one moves from Honokawai into Lahaina and Olowalu.

Crusher juice analyses for phosphate and potash have been made since 1922 with an occasional year left out. These figures on the whole check very nicely with the soil survey figures in showing the fields that are low and those that are high in the availability of these plant foods. There has been a slight improvement in the phosphates in the juice of the later harvestings compared with those before the heavy phosphate fertilization started. In some of the experiments of the N, NP, NK, NPK type, increases of about a hundred per cent have been noted in the juices from plots receiving phosphate over those not receiving this plant food. On the whole, it is much more difficult to show increases of phosphate in the juice of cane from phosphate fertilization than it is to show increased potash in juice from potash fertilization. This undoubtedly is due to the differences in amount of these two elements in the juices. The potash ranges from five to fifteen times the amount of phosphate in cane juices at Pioneer Mill Company. On other plantations this may range from one to twenty in mature cane.

TABLE Ib

AVERAGE OF CRUSHER JUICE ANALYSES (PER CENT BRIX) FOR FIELDS OF PIONEER MILL CO.

1922-1935

Field Groups	1922-1927 P_2O_5	1922-1927 K_2O	1928-1935 P_2O_5	1928-1935 K_2O	1922-1935 P_2O_5	1922-1935 K_2O
30-34	.068 (18)	1.150 (16)	.076 (8)	.747 (6)	.071 (26)	1.040 (22)
A	.053 (14)	.564 (11)	.071 (5)	.514 (5)	.058 (19)	.548 (16)
B	.071 (25)	.660 (23)	.103 (22)	.603 (16)	.086 (47)	.637 (39)
C	.110 (25)	1.857 (24)	.281 (21)	1.645 (16)	.188 (46)	1.772 (40)
D	.230 (35)	1.783 (34)	.281 (14)	1.672 (10)	.244 (49)	1.760 (44)
E	.056 (11)	.632 (10)	.069 (5)	.381 (5)	.060 (16)	.548 (15)
F	.056 (16)	.588 (15)	.083 (16)	.371 (13)	.070 (32)	.487 (28)
G	.065 (14)	.503 (13)	.076 (15)	.484 (11)	.071 (29)	.494 (24)
H	.100 (24)	1.470 (23)	.143 (23)	1.102 (15)	.121 (47)	1.325 (38)
I	.179 (18)	1.865 (15)	.177 (18)	1.093 (12)	.178 (36)	1.521 (27)
K	.100 (4)	1.019 (4)	.124 (6)	.916 (5)	.115 (10)	.961 (9)
LA	.073 (18)	.535 (18)	.103 (20)	.334 (16)	.089 (38)	.460 (34)
LB + Sch.	.100 (31)	.899 (29)	.124 (29)	.715 (20)	.113 (60)	.824 (49)
LC	.179 (22)	1.398 (22)	.173 (20)	1.447 (15)	.176 (42)	1.418 (37)
LD	.205 (15)	1.590 (15)	.195 (12)	1.433 (9)	.200 (27)	1.530 (24)
O	.236 (46)	1.843 (44)	.273 (31)	1.511 (26)	.251 (77)	1.720 (70)
MA	.082 (11)	.659 (10)	.107 (13)	.769 (9)	.096 (24)	.716 (19)
MB	.106 (17)	.930 (17)	.106 (15)	1.248 (9)	.106 (32)	1.040 (26)
MC	.155 (22)	1.515 (20)	.143 (22)	1.365 (20)	.149 (44)	1.440 (40)
MD	.252 (32)	1.739 (25)	.229 (21)	1.690 (18)	.240 (53)	1.689 (43)
Olowalu ..			.213 (54)	.824 (55)		

Each figure in parenthesis represents the number of times the fields in each group have been harvested.

Each figure not in parenthesis represents averages of averages secured from several samples in each field.

In Table Ib will be found the averages of crusher juice analyses per cent Brix for the fields of Pioneer during the years 1922 to 1935. These are grouped in the same way as in Table Ia for soil figures. These figures represent averages of 808 field harvestings for phosphate and 699 for potash. Each of these field harvestings represents an average of several analyses made while the field was in process of being harvested, so thousands of analyses make up these summaries. The period from 1922 to 1927 is given separately from that of 1928 to 1935, because the big increase in nitrogen and phosphate and the medium increase in potash fertilization for the plantation practice took place in the 1928 crop, as is shown in Table I. Please note the close similarity in the changes in these figures to the changes in the soil figures mentioned above. The second period (1928-1935) shows, in general, higher

phosphate figures and lower potash figures than the early analyses. The reverse should have been the natural expectation because of the change from crops averaging above 23 months of age to those of today averaging just below 20 months.

A study of these figures in greater detail shows that the larger increases in phosphate in the juice are from the areas getting the increased phosphate fertilization. These figures, together with other data, show that the plantation is undoubtedly getting much value from the increased phosphate fertilization. The steady decrease in potash throughout this period is somewhat alarming but only so in the mountain-water areas where the figures are low. These crusher juice figures, together with the low soil figures and the experimental data showing response to potash in these same areas, make it quite necessary to increase potash applications to these fields. This is spoken of again later under the experiments on potash.

A very striking set of figures can be shown by dividing the fields in the LB group that received mostly mountain water since 1931 or thereabouts, and those that received mostly pump water. All these fields previous to that time had pump and mountain water almost equally distributed.

	P_2O_5 Per Cent Brix	K_2O Per Cent Brix
LB fields—mountain water	.115	.574
LB fields—pump water	.137	.977

Compare these with the previous period and you will easily see how quickly the potash in crusher juice figures drops when pump water is no longer applied.

During the years 1924 and 1925 a fertilizer practice using only straight materials was followed, and no potash was applied except through the use of molasses in a very few areas and the application of pump waters high in potash. Undoubtedly this potash in pump water must be of value as a fertilizer, for a comparison of the crusher juice potash analyses of the cane from fields receiving pump water and those just across the pump ditch receiving mountain water shows a very much higher figure for the pump water treatment.

The early tests harvested soon showed the plantation authorities that increased amounts of phosphates and nitrogen were very necessary, and that potash was needed to a somewhat lesser degree, but was still quite necessary. On the strength of this a change to the use of mixed fertilizers was made, first using the Oahu formula 9-9-6 and then mixtures made up for their own conditions. The various changes in the practices given in Table I have been brought about through the results of the experiments harvested, and these will be discussed under separate headings of amounts, time of application and forms of the various plant foods. However, before embarking on this discussion, a few points should be brought out in regard to experiments of the type carried out at Pioneer. The maximum and minimum treatments have invariably been next to each other in the field. Those of you who are at all familiar with border effect of fertilizer experiments must therefore realize that the minimum treatment benefits at the expense of the maximum. The greater the difference in growth from the fertilizer treatments, the greater becomes this robbing of one to help the other. Therefore, the minimum treatment is not a true representation of what the plantation field would be like if handled by the minimum treatment, nor would the maximum one be either. It becomes necessary, therefore, to use all

experimental data as indication of a trend in one way or the other and not as the result of a certain treatment. Maybe the oft-heard expression "depressed yields from higher applications" can be partly explained in this way. Details of time of application obtained in some experiments cannot always be incorporated in all experiments, so a great deal of good common sense is required in utilizing all the data available in arriving at a sane fertilizer policy, even when some experimental results point against them.

It would be a bit less confusing to discuss the experiments in their order but it would require much more time and space than the writer has available. He will therefore group these tests into those of the various plant foods. Each of these groupings cover several years of harvesting and in each the amounts of plant food were changed, both as to the variable and as to the supplementary doses of other elements, but the general averages and listings show exceedingly strong trends that can be utilized with a great deal of reliability. A study of the details of these tests would be well worth while.

Nitrogen

The tons-sugar-per-acre yield from amounts-of-nitrogen tests over the whole plantation and throughout the years from 1921 to 1934 are listed in Table II. These 89 harvestings show that the optimum application is somewhere between 200 and 300 pounds of nitrogen per acre. In a study of the tests having larger supplementary doses of plant foods, those having the larger share of the nitrogen in the first season and those having the second-season application split into two, it becomes apparent that the greatest economical response is closer to the higher figure given above, that is, 300, than it is to the lower. In utilizing this figure in a plantation schedule, the other factors of location, time of year, length of crop, water supply and variety must enter the problem.

There has been an almost consistent increase in quality ratio with increased amounts of nitrogen throughout all these tests. Even with this change in quality there has nearly always been sufficient increased sugar production to take care of the poorer juices and still give an added profit.

In the tests of the 1927 crop and those prior to that year, the amounts-of-nitrogen experiments had the variables in the second season while in later years the variables were in the "boom stage" period of the first season. As pointed out above, the maximum yields seldom exceeded the 200-pounds-per-acre application in the earlier harvests. Later with the first-season variables the maximum yields often exceeded the 250-pounds-per-acre point. The first-season fertilization in the older tests was limited to 100 pounds of nitrogen regardless of time of starting but this was later raised to 140 pounds per acre. In the earlier tests the nitrogen was often applied in one dose each season. It can be seen from our present-day knowledge that this would hardly give the best yields.

At first only a few number-of-application tests were started, and they strongly indicated better yields from more than one application each season. Later, with the larger amounts of plant foods used, these results became even truer. In Table III will be found the sugar-per-acre yields of one versus two applications of the same amount of nitrogen in the second season. The average of these twenty-six comparisons gives 10.11 tons of sugar per acre for one dose against 10.55 tons of sugar

TABLE II

TONS OF SUGAR PER ACRE IN NITROGEN EXPERIMENTS AT PIONEER

Expt. and Field	Year	Plant Food P_2O_5	Plant Food K_2O	Pounds per Acre 100	150	200	250	300	350
2 (B6)	1921	varied		6.58	**7.37**	7.22	7.30		
	1923	varied		5.71	6.88	7.30	**7.65**		
	1925	90	0	5.94	6.39	**7.19**	7.16		
14 (B4)	1925	100	0	13.38	13.81	14.19	**14.36**		
	1927	150	100		9.21	9.29	9.87	**10.18**	
	1929	300	250		7.33	8.77	8.81	**9.16**	
	1930	250	200		6.40	6.73	6.93	**7.02**	
16 (32)	1925	100	0	10.75	10.70	**11.17**	10.98		
	1927	150	100		8.03	8.37	**8.51**	8.51	
	1929	300	250		7.72	8.62	**9.07**	8.48	
	1931	250	200		9.18	9.65	**10.03**	9.59	
19 (LA7)	1925	100	0	12.91	13.51	13.90	**15.41**		
	1927	150	100		11.84	11.96	**12.07**	11.56	
	1928	300	250		7.15	7.50	7.75	**7.80**	
	1930	300	250		9.34	9.36	9.85	**10.96**	
	1931	300	200			8.52 8.61	8.70	**10.08**	
23 (G2)	1925	100	50		10.15	10.58	**11.28**	11.23	
	1927	150	100		7.94	8.99	9.29	**9.62**	
	1928	300	250		7.32	**9.42**	9.15	8.38	
	1930	300	250			9.51	10.59	9.86	**11.53**
	1932	300	250			11.37	11.50	11.64	**11.53**
25 (08)	1925	100	0	9.59	9.96	**10.65**	9.82		
	1926	100	50	7.14	7.33	**7.57**	7.22		
	1928	150	100		8.97	9.13	**9.22**	8.83	
30 (A5)	1926	100	50		6.32	6.07	6.36	**6.91**	
	1928	200	150	5.82	**7.27**	6.46	6.53		
32 (B1)	1926	100	50		13.30	13.80	13.90	**14.49**	
	1928	200	150			10.22	9.96	**11.03**	10.96
	1930	300	250			9.09	8.91	8.95	**9.75**
	1932	300	250			7.38	8.23	**9.11**	8.92
34 (30)	1926	100	50		10.67	11.25	**11.50**	11.32	
	1928	200	150		10.43	**10.63**	10.50	10.54	
	1930	300	250		10.83	**12.08**	11.73	11.98	
	1932	300	250		11.29	11.94	**12.53**	11.63	
36 (C3)	1926	100	50	10.43	9.60	10.38	**10.93**		
	1928	150	100		10.44	11.10	10.81	**11.38**	
	1930	300	250			9.22	9.38	9.03	**9.39**
	1931	300	250			7.22	7.66	**7.85**	7.48
49 (E2)	1927	150	100		9.49	9.66	9.70	**10.22**	
	1929	300	250		11.86	12.05	12.91	**13.44**	
	1931	250	200		10.37	11.34	11.87	**12.51**	
62 (MA6)	1927	150	100		11.58	**13.26**	12.23	12.01	
	1929	300	250		8.75	8.91	**10.92**	10.11	
	1931	250	200			8.46	10.30	**10.53**	
67 (B3)	1928	200	150			**14.43**	14.35	13.90	13.36
	1930	210	143			11.52	12.17	**12.32**	12.11

TABLE II—(Continued)

TONS OF SUGAR PER ACRE IN NITROGEN EXPERIMENTS AT PIONEER

Expt. and Field	Year	Plant Food P_2O_5	Plant Food K_2O	Pounds per Acre 100	150	200	250	300	350
89 (B6)	1932	300	250			13.92	**13.99**	13.29	13.21
	1934	300	250			11.95	12.18	11.71	**12.21**
93 (34)	1933	250	200		10.44	10.90	**11.24**	11.24	
101 (E1)	1933	250	200			**11.54**	11.40	11.34	11.54
105 (20)	1933	150	150		10.58	**10.93**	10.81		
	1934	100	200		8.21	**8.55**	8.30		
109 (5)	1933	150	150		**6.62**	6.58	6.11		
215 (32A)	1929	240	160			9.56	9.74	**10.26**	
217 (A3)	1929	240	160			7.14	**7.63**		
218 (B6)	1929	240	160			**14.08**	13.74	13.65	
223 (C6)	1929	236	157				10.72	**11.72**	11.54
	1931	236	157				11.06	**11.24**	10.34
227 (LA3)	1929	240	160				**10.84**	10.39	
217 (A3)	1927	90	60		6.32	**6.59**			
223 (C6)	1927	90	60		9.33		9.99	9.51	
Fd. 32	1927	90	60		6.90		**7.32**		
Fd. MC2	1928	90	60				10.85	**12.23**	
Fd. F5	1928	158	105				9.45	**10.05**	
LA2	1927	90	60			13.76	12.94	**14.00**	
LA5	1927	90	60			9.74	9.71	**9.77**	
248 (41)	1927	90	60			**12.75**	12.33		
LB4B	1927	0	0			6.46	**6.61**		
LB6	1927	0	0			**8.31**	7.96		
LC5	1927	0	0			**9.13**	9.08		
MD2	1927	0	0			6.94	**7.93**		
214 (33)	1929	236	157			**9.37**	8.80		
214 (33)	1929	236	157			**9.74**	9.28		
214 (33)	1931	236	157				**10.46**	9.89	
214 (33)	1931	236	157				**10.66**	9.27	
219 (B7)	1929	236	157			**11.80**	11.45		
	1929	236	157			12.41	**12.76**		
	1931	236	157				11.33	**11.83**	
	1931	236	157				**12.83**	12.72	
225 (F2)	1929	240	160			10.42	**11.35**		
	1929	240	160			11.30	**11.48**		
228 (LA4)	1929	240	160			**12.69**	12.23		
	1929	240	160			12.16	**12.54**		
	1930	240	160			**9.63**	9.42		
	1930	240	160			9.27	**10.11**		
231 (07)	1929	90	60			**10.28**	10.24		
	1929	90	60			**11.17**	10.98		
	1931	90	60			**11.25**	10.00		
	1931	90	60			**11.48**	11.01		
Total high yielders in each treatment.....				3	26	29	26	5	

Total number of harvestings—89.

Bold faced figures represent the highest yielder in each experiment.

TABLE III

TONS OF SUGAR PER ACRE COMPARING ONE WITH TWO APPLICATIONS IN THE SECOND SEASON AT PIONEER

Expt. and Field	Crop Year	N	P_2O_5	K_2O	One	Two
5 (B6)	1921	200	70	37.5	6.84	6.86
	1923	200	70	37.5	7.79	8.16
	1925	200	92		7.41	7.81
LB4a	1927	228			9.23	8.95
LLSL	1927	264	90	60	10.90	11.50
MC6	1927	264	90	60	8.85	9.17
260 (F3)	1930	250	236	157	8.93	10.13
261 (LB2)	1930	250	236	157	10.36	10.64
214 (33)	1929	225	236	157	9.37	9.74
	1929	265	236	157	8.80	9.28
	1931	253	219	120	10.46	10.66
	1931	303	219	120	9.89	9.27
219 (B7)	1929	227	236	157	11.80	12.41
	1929	267	236	157	11.45	12.76
	1931	253	236	157	11.33	12.83
	1931	303	236	157	11.83	12.72
225 (F2)	1929	227	240	160	10.42	11.30
	1929	267	240	160	11.35	11.48
228 (LA4)	1929	227	240	160	12.69	12.16
	1929	267	240	160	12.23	12.54
	1930	227	240	160	9.63	9.27
	1930	267	240	160	9.42	10.11
231 (O7)	1929	227	90	60	10.28	11.17
	1929	267	90	60	10.24	10.98
	1931	215	90	60	11.25	11.48
	1931	252	90	60	10.00	11.01
Total of 26 tests				Average	10.11	10.55

for two doses. Seven tests harvested in 1934, comparing 102 pounds of nitrogen divided into three doses, with two doses in the last applications of short ratoons, gave in tons of sugar per acre 7.66 for two and 7.72 for three.

The time-of-application-of-nitrogen tests, although fewer in number, are interesting. In Table IV will be found the amounts of nitrogen and age at which these were applied. The results of the tests are also found in that table. They show how strikingly different yields may become when nitrogen is not applied at the proper time. As was later found out, applications of nitrogen as large as those used in these tests were better divided into two, and we can see from Experiment 56 that the dividing of the first 120 pounds into two doses was a better practice. We can also see from a study of the age of cane (given in Table IV in parentheses following the amount of nitrogen) that the best yields resulted when the largest amount of nitrogen went on in the "boom stage" of growth, or from about three to ten months of age. When too much went on, too early or too late, the yields as well as the juice quality suffered.

These tests also show that if the period between the last first-season application and the first second-season dose was too long, and this was still within the

TABLE IV

TIME OF APPLICATION OF NITROGEN AT PIONEER

Expt.	Treatment	Pounds of N. per Acre — 1st Season 1	1st Season 2	1st Season 3 (Nov.)	2nd Season 4 (Feb.)	2nd Season 5 (Apr.)
55	N	120 (3)	0	0	120 (9)	0
	O	120 (3)	0	120 (6)	0	0
	P	60 (3)	0	60 (6)	0	120 (11)
	Q	120 (3)	0	60 (6)	0	60 (11)
56	N	50 (2)	70 (4)	0	120 (10)	0
	O	50 (2)	70 (4)	120 (7)	0	0
	P	50 (2)	10 (4)	60 (7)	0	120 (12)
	Q	50 (2)	70 (4)	60 (7)	0	60 (12)
57	N	100 (3)	20 (4)	0	120 (10)	0
	O	100 (3)	20 (4)	120 (7)	0	0
	P	100 (3)	0	20 (7)	0	120 (12)
	Q	100 (3)	20 (4)	60 (7)	0	60 (12)

Figures in parenthesis signify months of age when applied.

Results:

	Expt. 55			Expt. 56			Expt. 57		
	T.C.	Q.R.	T.S.	T.C.	Q.R.	T.S.	T.C.	Q.R.	T.S.
N	67.35	7.96	8.46	74.68	8.74	8.54	51.71	6.88	7.52
O	58.52	8.03	7.29	77.28	8.51	9.08	47.74	6.72	7.10
P	57.81	7.95	7.27	71.82	8.81	8.15	39.74	6.92	5.74
Q	59.01	7.55	7.82	73.78	8.72	8.46	44.04	6.88	6.40

"boom stage" period of growth, there was a big curtailment in yield. Other tests have shown that if too long a period elapses between the two second-season applications, forcing the last one late into the spring, there is also a loss in yield due to poorer juices because of the late application. The time of year these applications can be made, very early or later, the time the crop will be harvested and the age of cane should all govern the period when these applications should be made. A longer period should elapse between these applications when the first is applied very early, and yet if the crop comes off early the next year these applications should come closer. Under Pioneer conditions, the writer feels that 100 pounds of nitrogen the second season is about the maximum that should be applied, unless the crop was started very late the year before and is to be cut late the next crop.

In a later series of tests on placing fertilizer with the seed, it was shown that this was a great help for maximum yields. It was also shown that as little as 25 pounds of nitrogen with the seed and 25 pounds one month later, when compared with placing 50 pounds on one month after planting, carried a significant gain in sugar and juice quality through to harvesting. Other tests on applying the larger share of nitrogen in the "boom stage" gave better yields for these treatments. It also became quite apparent that the soil type and time of year were very important considerations as to the time to apply nitrogen. The open, porous soils with poorer water-holding capacity required smaller doses applied oftener. The tight, fine silt

soils could stand large applications. The boom stage of growth started much sooner in later cut fields than in very early cut fields, and much sooner in the hotter Lahaina and Olowalu sections than in the upper sections of Puukoli, Wahikuli and Honokawai. Variations were therefore tried out in the different fields and sections so that today we find quite a range of practices in vogue.

An average of four tests comparing nitrate of soda with leunasalpeter in the second season of 1929 and 1930 gave the following figures:

	T. C.	Q. R.	T. S.
Nitrate of soda	52.90	7.24	7.33
Leunasalpeter	56.13	7.34	7.63

An average of four tests comparing calurea with sulfate of ammonia in the second season of 1932 gave:

	T. C.	Q. R.	T. S.
Calurea	65.92	7.1	9.26
Sulfate of ammonia	71.25	7.2	9.93

Averaging twenty tests comparing nitrate of soda with sulfate of ammonia in the second season in the 1930 to 1933 crops gave:

	T. C.	Q. R.	T. S.
Nitrate of soda	74.40	7.58	9.86
Sulfate of ammonia	75.66	7.67	9.92

Many of these last tests were studied for changes in pH due to fertilization. More often than not the sulfate changed the pH towards the alkaline side, but a general trend in some tests seemed to be only very slightly towards acidity. In the light of work done in other crops and in sugar cane at Oahu Sugar Company, Limited, the use of ammoniacal nitrogen has a very decided influence on the uptake of phosphates. So in areas very deficient in phosphates, like many of those at Pioneer, this is a decided secondary benefit to cane yields.

Molasses

Since the use of molasses as a fertilizer is so closely tied up with nitrogen, the discussion on this material is brought in at this point.

With the use of molasses in the irrigation water applied to fields, it became imperative to apply sulfate of ammonia along with the molasses to prevent a check in cane growth through denitrification in the soil set up by the microbiological decomposition. But from the first test harvested in 1924, it was apparent that the percentage response to molasses was greatest where the nitrogen was limited, showing that the nitrogen in molasses must be of value. It has also been apparent ever since this first test, that optimum nitrogen applications were necessary to give larger yields. In areas where the nitrogen had a tendency to be produced in large quantities or was found in greater quantities, this application of molasses had a decidedly depressing effect on juice quality. On exceedingly porous or gravelly soils the application of large amounts of molasses had a very beneficial effect on yield and ratooning. Much of this is undoubtedly due to the improvement in water-holding capacity of these soils. On the other hand, there are areas of very fine, silty

red soils that can be harmed by heavy applications of molasses. This is no doubt brought about through the same agency that benefits the soil types just mentioned above. The tightening of these soils so that water cannot penetrate to the cane roots will naturally depress cane growth for a period of time. This may be more marked in areas of straight lines on grades where the water will have a tendency to run too fast due to this tightness. As the cane grows older the roots may open up the soil, the trash may slow down the water flow and the plant and water both remove some of the controlling features of the molasses in the soil, so that the crop area will show a decided improvement in growth as if some unknown application of material had been made.

On the whole, however, molasses has been shown to have a wonderful effect on soil fertility equal to the effect of fallowing land for several years. The analyses of soils at periodic dates after application of molasses at Pioneer have shown a tremendous improvement in available plant foods. These points were very thoroughly covered by the writer in articles on "Molasses as a Fertilizer" in the Proceedings of the Hawaiian Sugar Planters' Association for 1927 and 1928. In areas of heavy nut grass it seems as though there should be at least three bags of sulfate of ammonia applied with the molasses instead of the regular two.

Phosphate

In the thirty or more amounts-of-phosphate-to-apply tests harvested, which are listed in Table V, it has been clearly shown that in the areas that were deficient in this nutrient by soil analyses, there has been a distinct response to phosphate up to 200 pounds per acre. In some areas there have been responses to larger amounts, and in still other areas there have been responses only to smaller amounts. On the whole, the areas very low in phosphates in the crusher juice show distinct responses to phosphates.

The later tests, on amounts of phosphate installed in new locations, have not shown as large responses to phosphate as the earlier ones. This is undoubtedly due to the larger applications to plantation fields in later years creating a reserve supply, while the earlier fields had no reserve because of very small applications of phosphate in the past. This would strongly indicate that phosphate reserves can be built up within a few years, by using fair amounts of phosphate. The question now arises on how we may make use of this reserve in economizing on fertilizer. In amounts-of-phosphate tests, where there is no distinct deficiency of phosphate, we often find poorer juices with increased applications. The opposite is often the case where a real deficiency of phosphates is found. Under the latter conditions, the writer feels that it would be most advisable to put part of the phosphate on in the second season or apply extra phosphate at that time.

In a series of five experiments harvested twenty-two times, it has been clearly shown that superphosphate was distinctly superior to reverted and raw rock phosphates. Table VI shows these figures in detail. Even when 300 pounds of phosphate per acre are used, the difference in cost of super and raw rock furnishing this would be made up three times in the price of increased sugar per acre obtained from super over raw rock. A study of the figures does not show any equalization of the yields of the super and raw rock plots even after ten years. This shows that there is no more residual phosphate in the raw rock plots than in the super.

TABLE V

TONS OF SUGAR PER ACRE IN PHOSPHATE EXPERIMENTS AT PIONEER MILL COMPANY

Expt. and Field	Year	Plant Food N	Plant Food K_2O	Pounds per Acre 0	50	100	150	200	300	400
3 (B6)	1921	200	0	6.24	6.04	6.26	**6.41**			
	1923	200	0	6.61	6.76	7.29	**7.61**			
	1925	200	0	6.08	6.72	**7.09**	6.92			
45 (LA7)	1927	240	100			11.37		**12.21**	11.97	
	1928	260	250					**9.95**	9.87	7.57
	1930	260	250			12.03		**12.27**	10.86	
	1931	263	250			8.89		**10.43**	9.76	
67 (B3)	1928	240	150	12.73		13.13		**13.14**	13.02	
	1930	240	150	10.67		11.47		11.71	**11.87**	
50 (E2)	1927	240	100	9.61		10.65		**11.18**	9.82	
	1929	260	250			12.56		12.68	**13.43**	12.56
	1931	260	200			12.04		12.27	**12.55**	11.82
51 (B7)	1927	240	100	10.02		9.96		10.00	**10.58**	
	1929	260	250			13.23		12.90	**14.04**	13.44
	1931	260	200			12.30		12.83	13.25	**13.36**
	1933	253	200			12.27		**12.66**	12.37	12.34
52 (B4)	1927	240	100	10.58		10.11		10.61	**11.20**	
	1929	260	250			10.53		10.44	**10.73**	10.49
53 (33)	1927	240	100	12.14		12.23		**13.01**	12.50	
	1929	260	250			10.53		10.44	**10.73**	10.49
	1931	260	200			10.25		10.24	10.26	10.10
	1933	253	200			8.81		8.46	8.84	8.42
54 (F2)	1927	240	100	10.12		10.92		**11.25**		
72 (G2)	1930	260	250			10.55		10.77	**11.15**	10.89
79 (C3)	1931	260	250				8.69	8.94	**9.12**	
82 (30)	1932	260	250				11.89	11.75	**11.96**	
90 (B6)	1932	256	250				**14.78**	14.43	14.47	
	1934	256	250				12.46	**12.58**	12.45	
94 (34)	1933	253	200			10.63		10.66	**10.77**	
99 (E1)	1933	253	200			10.47		**11.33**	10.78	

Bold faced figures show the highest yielding treatment.

A Mitscherlich pot test run on the soils of one of these tests (Experiment 24 in Field G2) after the fifth harvesting in 1932, or nine years after the test was started, shows available phosphate of over 500 pounds per acre-foot for super and 47 per acre-foot for raw rock. The K_2O figures are 345 for super and 445 for raw rock. All five of these tests have had one soil analysis made by the one per cent citric acid method during the life of the crop and after the tests have been about eight years old. These indicate differences of higher pH and higher lime and potash contents for the raw rock treatment. The crusher juice figures all have lower K_2O contents for the raw rock plots over the super. The continued use of raw rock therefore seems to build up potash in the soil by not allowing it to be removed in the cane crop. The Mitscherlich tests therefore showed this increased potash. Another pot test was run at Pioneer with sudan grass on soil from Experiment 21 in Field LA7. Surface and subsoil were taken from the super and raw

TABLE VI

FORMS-OF-PHOSPHATE EXPERIMENTS AT PIONEER

Expt. and Field	Crop Year	Plant Food			Super			Reverted			Raw Rock		
		N	P_2O_5	K_2O	T.C.	Q.R.	T.S.	T.C.	Q.R.	T.S.	T.C.	Q.R.	T.S.
12 (B4)	1925	180	100	0	90.8	6.40	14.20	90.2	6.40	14.10	88.2	6.58	13.20
	1927	190	150	100	71.3	7.06	10.10	71.8	7.01	10.23	67.1	6.96	9.63
	1929	260	300	250	60.4	6.76	8.93	62.1	6.77	9.17	60.1	6.88	8.74
	1930	260	250	200	44.7	6.73	6.64	46.5	7.00	6.65	43.9	6.73	6.53
15 (32)	1925	180	100	0	83.9	7.20	11.65	82.4	8.10	10.18	81.5	7.20	11.31
	1927	190	150	100	67.8	8.15	8.32	69.2	8.16	8.48	66.0	8.08	8.16
	1929	260	300	250	68.3	6.65	10.27	67.0	6.71	9.99	67.7	6.65	10.18
	1931	260	250	200	76.2	7.33	10.40	72.4	7.26	9.97	72.2	7.34	9.84
21 (LA7)	1925	180	100	0	94.5	7.30	12.94	96.6	7.20	13.41	97.1	7.09	13.70
	1927	190	150	100	79.4	7.18	11.06	75.6	7.24	10.44	72.1	7.10	10.15
	1928	260	300	250	57.6	8.17	7.05	56.8	7.75	7.33	51.4	7.72	6.65
	1930	260	250	200	75.9	7.70	9.86	78.1	7.80	10.01	74.1	7.90	9.38
	1931	263	300	250	64.8	7.64	8.48	67.8	7.85	8.64	64.0	7.85	8.15
24 (G2)	1925	177	100	0	76.2	6.23	12.22	67.8	6.30	10.78	70.4	6.30	11.18
	1927	240	150	100	75.4	7.90	9.53	79.3	8.22	9.65	78.6	7.87	9.99
	1928	260	300	250	65.5	7.67	8.55	64.0	7.24	8.85	65.4	7.02	9.31
	1930	260	300	250	78.1	7.40	10.55	77.2	7.30	10.58	70.9	8.30	8.65
	1932	256	300	250	94.6	8.31	11.38	88.9	8.16	10.89	95.9	8.44	11.36
	1933	256	300	250	64.3	7.00	9.19	56.3	6.86	8.21	59.8	6.76	8.85
47 (E2)	1927	240	150	100	81.7	7.78	10.51	80.1	7.80	10.28	82.1	7.73	10.62
	1929	260	300	250	86.3	6.63	13.01	84.2	6.70	12.57	83.3	6.66	12.51
	1931	260	250	200	88.7	6.80	13.05	86.9	6.95	12.50	79.2	6.76	11.72
Average of 22 tests.....					74.8	7.27	10.36	73.7	7.31	10.13	72.3	7.27	9.99

rock plots and treated with super and raw rock in the combinations listed below. The yields in grams per pot are also given:

	Expt. Treatment	Pot Treatment	Yield
Surface soil	super	super	530
	super	raw rock	550
	raw rock	super	678
	raw rock	raw rock	500
Subsoil	super	super	646
	super	raw rock	608
	super	none	576
	raw rock	super	540
	raw rock	raw rock	424
	raw rock	none	468

What is it that seems to be depressing the soil productivity by continued use of raw rock?

In two tests comparing treble superphosphate (A), raw rock (B), ammophos (C), and a mixture of these three, half of which is raw rock (D), the results are as follows:

	T. C.	Q. R.	T. S.
A	68.9	6.67	10.33
B	65.2	6.61	9.86
C	72.4	6.68	10.84
D	70.1	6.66	10.53

	T. C.	Q. R.	T. S.
A	90.6	7.37	12.29
B	85.1	7.29	11.67
C	91.8	7.36	12.47
D	85.9	7.29	11.78

On the strength of these last two tests the plantation's mixed fertilizers were changed from one like treatment D above to newer ones using ammophos predominately. This change had been attempted before, but because of changes in fertilizer prices during the absence of the writer in Puerto Rico, a return to the raw rock-super mixture was made.

Besides all the amounts-of-phosphate tests, there are the many plant food or PK tests which show very clearly the value of phosphates to many of the fields of Pioneer Mill Company.

Potash

The twenty harvestings of amounts-of-potash tests, listed in Table VII, show that on the whole there is no uniform demand for potash, but that in certain areas a very marked response can be secured for potash applications over and above the 120-pound mark used in the past. This has been made use of in recent changes of fertilizer policies so that on these deficient areas the application has been raised to a minimum of 175 pounds. Very unfortunately, a few years ago Experiment 64,

TABLE VII

TONS OF SUGAR PER ACRE IN POTASH EXPERIMENTS AT PIONEER

Expt. and Field	Crop Year	Plant Food N	Plant Food P_2O_5	Pounds per Acre 0	60	120	180	240	300	360
40 (O8)	1926	180	100	8.9	9.83	9.06	**9.93**			
	1928				11.70		11.76	**12.30**		11.83
46 (E1)	1927	240	90	7.4	**8.87**					
67 (B3)	1928	240	200	**13.74**		13.46	13.20		12.58	
	1930	240	200	**11.53**		11.43	11.38		11.14	
64 (G3)	1927	240	200		10.71	11.06	11.46	**11.77**		
	1928	260	300		9.76	**10.27**		10.06	9.21	
	1930	260	300		11.22	11.88		11.60	**12.06**	
	1932	256	300		10.94	12.04		**12.32**	12.02	
	1933	256	300		9.91	10.57		**10.80**	11.17	
69 (MA6)	1929	260	300		11.21	12.52		**13.06**	12.17	
	1931	260	250		10.57	**10.82**		10.33	9.96	
70 (32)	1929	260	300		12.37	**12.73**		12.61	13.16	
	1931	260	250		11.16	**11.60**		11.21	11.23	
	1933	256	250	**11.35**	11.12	11.15		10.99		
71 (E2)	1929	260	300		10.23	10.73		**10.82**	10.75	
	1931	260	250		11.28	11.46		**11.68**	11.35	
	1933	256	250	9.90	10.10	10.41		**10.71**		
80 (C3)	1930	260	300	**8.43**		8.45		8.10	8.46	
81 (LA7)	1931	263	300	8.04		8.26	8.19		**9.14**	
	1933	256	300	10.95		10.76	10.89		**12.59**	
	1934	260	300	6.45		6.93	8.31		**8.49**	
83 (30)	1932	260	300	11.36		11.76	**11.91**		11.79	
88 (B6)	1932	256	300	12.59		**13.76**	13.14		13.51	
	1934	256	300	10.85		**11.44**	11.27		11.25	
95 (34)	1933	253	250	8.64		8.60	**9.12**		9.11	
B1	1934	252	207	9.44		**10.18**				
4 (B3)	1921	200	0			7.31		**7.36**		
	1923	200	0			7.31		**7.81**		
	1925	200	0			7.01		**7.11**		

Bold faced figures represent the highest yielding treatment.

which should have been a key experiment for areas low in potash by soil analyses, was laid out with the plots labeled in the reverse order to the usual method in labeling increased amounts of a material. The plots were labeled D, C, B, A, for increasing amounts of potash. On the next crop fertilization, these plots were fertilized without reference to this method of labeling as the stakes were all in and the fertilizer was put on in the usual method of increased amounts as the letters went down the alphabet. The residual effect of the first crop fertilization was all evened up as a study of the yields in 1927 and 1928 will show (Table VII). During the next few months the plot labels were all changed to V, W, X and Y and the maps were also changed, but no comment was made in any of the notes on this experiment. The writer, however, was aware of this at the time of fertilization and recorded it in his notes. In spite of this reversal of plots you will please note the distinct response to potash in a more marked degree as each succeeding crop was harvested.

TABLE VIII

TONS OF SUGAR PER ACRE IN PK EXPERIMENTS AT PIONEER

Expt. and Field	Crop Year	Plant Food N	P_2O_5	K_2O	N	NP	NK	NPK
4 (B6)	1921	200	100	100	7.19		7.33	7.57
	1923	200	100	100	6.97		7.56	7.53
	1925	200	100	100	6.91		7.06	7.48
7 (B2)	1924	180	100	50	8.99	9.27	9.15	9.31
	1926	180	100	50	6.43	7.15	6.96	7.20
	1928	240	200	150	6.43	7.83	6.46	7.42
8 (31)	1924	180	100	50	12.11	12.62	12.42	12.22
	1926	180	100	50	7.77	8.96	7.62	8.53
	1928	240	200	150	6.04	7.50	6.11	7.56
	1930	260	300	250	5.95	7.76	6.10	7.54
13 (B4)	1925	180	100	50	13.45	13.10	13.07	13.75
	1927	190	150	100	9.45	9.60	9.12	9.23
	1929	260	300	250	7.17	8.39	7.48	9.09
	1930	260	250	200	5.30	6.39	5.48	6.73
17 (32)	1925	180	100	50	10.16	9.89	9.65	9.95
	1927	190	150	100	6.62	8.03	6.65	7.76
	1929	260	300	250	7.24	8.12	7.24	8.41
	1931	260	250	200	6.98	9.14	7.34	9.77
20 (LA7)	1925	180	100	50	13.87	13.81	14.11	13.70
	1927	240	150	100	10.08	12.36	11.92	11.17
	1928	260	300	250	7.14	7.82	6.47	8.27
	1930	260	300	250	9.01	9.71	8.96	10.12
22 (G2)	1925	177	100	50	9.93	10.88	10.59	10.60
	1927	240	150	100	8.80	9.38	9.28	9.95
	1928	260	300	250	9.17	8.70	8.58	9.25
	1930	260	300	250	7.40	9.97	7.51	10.25
26 (O8)	1925	180	100	50	9.08	9.24	9.90	9.14
	1926	180	100	50	7.10	7.39	7.56	7.39
	1928	240	150	100	8.88	8.81	9.06	8.62
31 (A5)	1926	180	100	50	5.50	6.22	6.10	6.15
	1928	240	200	150	5.19	5.04	4.95	6.26
33 (B1)	1926	180	100	50	16.12	15.07	15.73	15.52
	1930	260	300	250	9.82	10.51	11.20	10.99
35 (30)	1926	180	100	50	8.38	10.47	9.25	10.47
	1928	180	200	150	7.22	10.09	7.12	10.42
	1930	260	300	250	6.62	11.30	6.63	11.34
37 (C3)	1926	180	100	50	10.65	10.85	10.05	10.40
	1928	240	150	100	10.93	11.21	11.23	11.50
	1930	260	300	250	8.71	9.68	8.84	9.54
48 (E2)	1927	240	150	100	8.98	8.32	8.10	9.25
	1929	260	300	250	11.05	11.46	12.13	12.73
	1931	260	250	200	9.17	11.03	9.49	11.68
63 (LB6)	1929	260	300	250	11.09	11.15	11.21	12.00
	1930	260	250	200	9.18	10.20	9.99	10.63
30E	1928	228	300	200		9.77	7.17	10.32
A3	1928	240	250	200		6.44	5.45	6.08
F4	1928	240	250	200		8.48	8.04	8.86
C2	1927	230	300	250		7.11	6.81	7.62
	1929	230	300	250		8.56	9.34	9.35
Average of those having all four treatments					8.76	9.62	8.94	9.80

The areas that were markedly deficient as shown by the old one per cent citric acid analyses in the 1922, 1926 and 1927 surveys are the very ones that show the large responses to increased potash. The G3, E2 and LA7 tests have continued to show what might be gained by higher potash applications in those districts.

In considering the potash found in pump waters as an available nutrient for plant growth, as mentioned above in comment on crusher juice analyses, one must remember that Maui waters are very high in pounds per million gallons. This is not true of pump waters on Oahu, and therefore what might be true of making use of the potash in these waters on Maui might not be true on Oahu.

Plant Food Balance

The fifty harvestings of experiments on N, NP, NK and NPK treatments are listed in Table VIII and averages arrived at for only those having all four treatments. It is again very interesting to show that there is a decided loss from nitrogen only, and that there are gains from both phosphate and potash on the average soil; but in arriving at a fertilizer policy each individual case deserves study and proper handling. It is of particular interest to point out a few of these tests in the list.

Experiment 48 in field E2 checks very nicely with other tests in this section of the plantation in showing the necessity of potash as well as phosphate in this soil type. Experiments 22 in G2, 20 in LA7, 13 in B4 and 17 in 32 all show this same point. The very marked increases for phosphate are the most prominent points in this table and readily check with other fertilizer results. However, the writer wishes to call your attention to Experiment 35 in field 30. The enormous differences in the phosphate treatments over the others can hardly be comprehended unless one really saw these tests in operation. The test was of such interest that quite a study was made of soil analyses and plant material analyses. It would require too much space and time to go into a discussion of these studies at this time, and since they were conducted along with similar tests in other areas, the comments should be reserved for a complete write-up. The writer felt that it would be of interest to return to the various plots the amount of fertilizer each had not received in comparison with the NPK treatment in the three crops, that is, the N plots would receive in one application all the phosphate and potash that the NPK plots had received in the three crops and so on throughout the other treatments NP and NK. There were, however, two of the seven plots in each treatment given the normal plantation fertilizer for the field. In the writer's opinion, some mistake was made in labeling the plots receiving only the plantation practice, and since the staking and mapping of the test was not completed till six months later, there is no way of settling the matter.

The average yields of each series of plots, regardless of whether it received only plantation practice or the increased plant food, are given herewith:

	T.C.	Q.R.	T.S.
N	88.2	7.67	11.55
NP	98.9	7.89	12.64
NK	89.7	7.92	11.32
NPK	95.7	7.82	12.24

Comparing these yields with those of the last crop and noting the percentage gains in sugar, we have:

	Tons Sugar per Acre		
	1930	1932	% Gain
N	6.62	11.55	74.5
NP	11.30	12.60	11.5
NK	6.63	11.32	71.0
NPK	11.34	12.24	7.5

The two poorer yielding treatments of the 1930 harvest have not regained the yielding power of the higher or phosphate treatments. This clearly points out that one cannot bring a field up to its maximum production within a crop, but that the effect is cumulative from residual fertilization. Many of the tests at Pioneer have clearly brought out this point, and in the writer's opinion the reverse idea must be true as well. In other words, if the yield is high from proper fertilization and one decides to economize on fertilizer, he may secure as fine yields within the range of probable error for a crop or two, but eventually the soil reserves will have been depleted to a point at which yields will drop materially.

In a closer study of these various tests and all other fertilizer tests at Pioneer, it is quite apparent that where proper amounts of plant food are used, yields are maintained at a high level through several crops. Where there are insufficient plant foods there are often very marked decreases between crops. This is true even for nitrogen as well as for the others. The smaller applications in plant food may show a decrease in yield gradually, but often show a rather abrupt one when the drain on soil reserves has reached a point at which it becomes almost impossible for the plant to secure the food. Crusher juice analyses have often shown a greater uptake of phosphates and potash when nitrogen only has been applied, than when all three plant foods are used.

In a study of the time to apply the mixed fertilizer, two tests were harvested comparing a complete fertilizer (A) vs. only phosphate and potash (B) vs. nothing with the seed (C). The latter treatment received its complete fertilizer one month later, and at the same time, the second treatment received its 50 pounds of nitrogen. The results of these two tests are interesting and are given herewith:

	T.C.	Q.R.	T.S.	T.C.	Q.R.	T.S.
A.....	84.20	7.4	11.38	90.79	6.6	13.76
B.....	87.44	7.4	11.82	96.65	6.6	14.64
C.....	80.61	7.4	10.89	95.89	6.7	14.31

These show how important it becomes to have phosphates and potash applied early. Similar tests on other plantations have clearly demonstrated this point, and the writer has drawn attention to this in other papers, showing that much depends on whether there is a deficiency of these elements or not. These figures also bring out the point that 50 pounds of nitrogen, or part of it, could be more effective at a later period. This was also shown in the test mentioned above having 25 pounds of nitrogen with the seed and 25 pounds one month later, in comparison with the 50 pounds applied one month later. (Both treatments received phosphate and potash with the seed.) As mentioned above, the significance of the gain in quality

and sugar for the 25 pounds with the seed was large; that fact then, coupled with these results, shows that 25 pounds of nitrogen with the seed is about the most profitable.

Several comparisons of the new, more concentrated fertilizers with the older forms gave yields in favor of the newer materials even when less plant food was applied with the new. A list of these follows:

Materials	Old	New
P.M.S. vs. A5	6.99	7.14
P.M.S. vs. A5	10.21	11.25
P.M.S. vs. A5	9.39	10.31
P.M.S. vs. A5	8.86	9.06
P.M.S. vs. A5	7.97	7.69
H.G. vs. A4	8.83	8.64
H.G. vs. A4	8.85	8.25
H.G. vs. A4	8.10	9.07
P.M.S. vs. A4	13.08	14.58
A6A vs. A17 + N.K.	8.31	7.99
A6A vs. A17 + N.K.	9.66	9.27
A6A vs. A17 + N.K.	6.66	7.47
A6A vs. A17 + N.K.	8.83	9.38
A6A vs. A17 + N.K.	8.78	8.12
A6A vs. A17 + N.K.	8.89	8.78

In the last series of the above comparisons, the plant food was 20 pounds of nitrogen, 12 pounds of phosphate and 11 pounds of potash less per acre, and the difference was all in the first three months of the crop. On the whole, the newer more concentrated fertilizers are much more economical to handle and give better returns.

A series of triangle fertilizer tests, after the plan of Schreiner of the United States Department of Agriculture, was harvested at Pioneer. Four of these were reported upon in the Technologists' Proceedings for 1930. Two more harvestings were subsequently made. All of these tests very clearly pointed out the vast differences in yield one can secure from different plant food balances. They also showed the differences in response to nitrogen, phosphate and potash on the various soil types of the plantation. They checked very nicely with other experimental data in showing the areas very deficient in certain plant foods. In general, these tests showed the best results from a ratio of about 250 pounds of nitrogen, 200 pounds of phosphate and 150 pounds of potash. Therefore, in the writer's opinion, it would be necessary to increase all three plant foods at the same time in attempting to find the optimum amount of each plant food to apply. This type of test has been harvested several times at Olaa in the last crop or two and has shown some very interesting results. Gains in cane and sugar without poorer juices were made with significant differences, but they were not economical. The point that should be emphasized is that quality of juice was not affected. This has always been the writer's contention, that when a proper balance of fertilizer is obtained,

quality will not be radically affected with increases in plant food, as has been demonstrated in many tests at Pioneer, as well as elsewhere.

Olowalu Section

Since this part of the plantation has only been under the supervision of Pioneer Mill Company in the last few years, the results of the tests harvested on those fields have not been averaged in all cases. Therefore a few comments on these soils alone are given herewith.

In a number of tests at Olowalu on amounts of phosphate, a high significance was found in better quality of juice without phosphates, while in three others with amounts of potash, a better quality was obtained with potash. In plant food tests on Olowalu soils, it has been demonstrated that nitrogen alone up to a little over 200 pounds per acre has given about the best yields. There is, however, an enormous response to large applications of filter cake and molasses. These must have altered the water-holding capacity of the soils and thus increased the yields. There are, however, in the pali lands soils of a different nature from the washed-in silt and gravel of the flats in Olowalu, and these will undoubtedly respond to a different fertilization. It must be remembered that the cropping cycle on these fields is a short one due to the slowing down of growth after a certain age has been attained; for this reason high applications of nitrogen do not seem to pay.

Mitscherlich Pot Studies

Several Pioneer soils have been studied by this method in the last few years. Many of these have been from experimental areas where distinct responses to fertilizers have been obtained. The results of these pot tests correlate very nicely with other data and show areas where potash and phosphate are low. The large responses to phosphate in many of these early harvestings at Pioneer have made these soils especially valuable to the Mitscherlich investigations, and much of their correlation data have been obtained from these soils. These pot tests have not given us many additional data when compared with the vast amount of data collected in the past from soil analyses, juice analyses and experiments, but it is interesting enough to note that they do correlate with these other data.

New Developments

A very extensive soil kit analyses—juice analyses—yield-of-crop data—correlation study is now under way. This will be well worth watching and should aid us in a policy of differential fertilization in parts of fields and should also help to bring up the general averages of fields.

Conclusions

In concluding an article of this nature, one could make a very broad statement to the effect that the results of fertilizer experiments have been almost entirely responsible for the changes in fertilizer policy on the plantation. It would have been very improbable and almost impossible to have made these changes without

the aid of field experiments and the contributory data secured from them, but a few points should be summarized to properly conclude the paper.

1. Experimental data have confirmed the general broad groupings of fields through soil surveys and crusher juice analyses and vice versa; the three lines of investigation having gone ahead simultaneously.

2. Experimental data have strongly indicated better yields from better utilization of the plant foods in the following ways:

A. Nitrogen:

1. Increased amounts to suit location, soil type, water supply, etc.
2. Several applications in both seasons, that is, at least three in the first and two in the second.
3. A greater share of nitrogen in the "boom stage" of growth.
4. Proper balances of other plant foods.
5. Proper time of application so that the first second-season fertilization should not be delayed too long after the last first-season one or too late in the "boom stage." (A delay here is a sure way to decrease yields.)
6. When applications of N are 50 pounds per acre the period between doses should be varied to suit the time of year. In the second season, this period should be more than one month when the first dose goes on in January or February.
7. Use of ammoniacal in preference to other forms of nitrogen.
8. Utilization of nitrogen from filter cake and molasses.

B. Phosphate:

1. Increased amounts to suit deficiencies as shown by experiments, soil analyses or crusher juice data.
2. More available forms such as super or ammophos.
3. Use of ammoniacal nitrogen.
4. Utilization of phosphates in filter mud.

C. Potash:

1. Increased amounts to suit deficiencies as shown by experiments, soil analyses or crusher juice data.
2. Utilization of potash from molasses and pump waters.

D. Balance of plant foods:

1. Better yield and juice quality when used in proper ratio to each other.
2. When used in sufficient amounts, yields are maintained. (This has been demonstrated in the big decreases between crops of plant and ratoon cane when there is insufficient plant food, while in other cases where plant foods are abundant there may be increases in yield.)

3. Strong indications are apparent that with proper fertilization good yields may be built up and maintained. The residual effect of fertilizer is more marked than we normally think. To bring back an area depleted of plant foods requires

more time than just one crop heavily fertilized. In other words, the effect of proper fertilization is cumulative. The reverse of this fact should also be stressed in these times when much consideration is being given to reduced fertilization in an attempt to save a few dollars in cost.

The able staffs of both the Pioneer Mill Company and the Experiment Station of the Hawaiian Sugar Planters' Association have been responsible for the carrying out of these experiments; much credit is due them for this work, and their results have been of valuable assistance in determining a proper fertilizer policy for the plantation. The work is not over yet and you will undoubtedly hear from the others today as to how the future policies will be changed and improved through further research. You can readily see the immense value such an amount of research can be in shaping the plantation practices, and the writer sincerely hopes that this may act as a stimulus to further experimentation on other plantations.

The Present Trend in Our Use of Fertilizer*

By R. J. Borden

The present trend in fertilizer usage on the sugar cane lands of these Islands is very definitely towards a differential fertilization; hence this discussion will center chiefly about some of the facts that are concerned with the adoption of a policy of differential fertilization.

In a general way, however, we begin to note some reduction in the total amounts of fertilizer being applied, especially in phosphate, in instances where more recent evidence has shown no gains from its application, and where soil analyses have indicated an apparent sufficiency of this plant food. There has not been much change in the total potash applications. A slight drop of perhaps 20 to 40 pounds in the nitrogen, chiefly in the later applications, has been noted on a number of plantations. There have been very few increases in the total amounts of any of the plant foods that are being applied, although there have been some adjustments in the distribution of these nutrients in an attempt to put more on some specific areas and correspondingly less on others. Evidently we have reached a peak in the total amounts per acre and the general trend will henceforth be downward.

We note a general reluctance, however, to accept a policy that calls for decreasing the present total fertilizer applications. This is perhaps very commendable, until such time as good evidence is presented to prove the economy of such a move. Most certainly should we approach this question of cutting down fertilizer applications in the same careful way that was formerly used when we decided to increase

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the amounts to be applied. Hence, we feel quite strongly that each case needs individual study, and I want to discuss with you today just a few of the things that will have to be considered.

Phosphate

First let us consider phosphate: a material that is rapidly fixed and therefore not subject to waste by luxury consumption or by leaching; which is needed in relatively small amounts but is very necessary in these small amounts; and which applied to our high phosphate-fixing soils in small amounts, is undoubtedly very ineffective in causing immediate increased yields. What should guide our policy with regard to phosphate fertilization: (1) A realization that it is perhaps easier to deplete the available phosphate reserve in our soil than it is to build it up. (2) A recognition of the fact that money invested in phosphate is a soil investment for the future and not simply a chargeable item of expense against the next crop to be cut. (3) A knowledge of the fact that there is little evidence to show that too much phosphate is harmful to the cane crop. (4) A knowledge that phosphate fertilizers are generally fixed by the soil at their point of application and that they should be put where the greatest number of feeding roots will be apt to contact this phosphate-satisfied soil. These points would tend to argue for ample phosphate applications, particularly at the time when the field is plowed and planted. Against this argument we have the one that says, "if the available supply of phosphate for this present crop is sufficient, we may leave phosphate out of the present crop fertilization." Is this sound? We have been advised for ages past that the storehouse of plant food (which includes phosphorus) in the soil is not inexhaustible, and that which we take out in the crop, we must ultimately return. If this is good logic then we ought to be able to square ourselves with Nature if we put back approximately 100 pounds of phosphate which our normal crop takes away. If you have been putting on this amount, or more, for some years past, then you have built up a reserve, and under the present economic conditions, you are just as much entitled to draw on this reserve as your plantation directors were entitled this year to pay unearned dividends from their reserve funds. If you have been building up the available phosphate in your soil, either by applications of phosphate in fertilizer materials or from filter cake (and remember that a 5-ton dressing of filter cake will put 100 to 150 pounds of P_2O_5 back), then you are indeed in a position to let your phosphate insurance carry you over. Also, if Nature is providing your soil with a sufficiency of available phosphate, I believe it would be wise to make use of it now, particularly for your ratoon crops, and think about a possible phosphate refund to your soil when the next plant crop goes in.

Where the evidence quite definitely indicates a phosphate deficiency, there should be, and generally is, no hesitation about applying phosphate fertilizer, but we should stand ready to face the facts as we find them and meet them accordingly.

Potash

With regard to potash, we have quite a different plant food material to consider. The volcanic lavas from which our soils have been formed contain a large amount of potash, but the weathered soils from this lava have lost about 60 per cent of this

potash. Analyses of cropped mauka soils compared with virgin mauka soils show that more of the potash has been lost from the cropped soil than can be accounted for in the crops removed. Thus it appears that available potash, if not taken up by the crop, is subject to loss by leaching. Maxwell makes the statement that the analysis of drainage waters from Hawaiian soils shows potash lost in this manner that is fully equivalent to that taken up by the crops. F. E. Hance's studies on the irrigation waters from central Maui show us the fate of the potash that has become available in the Island soils. The sugar cane crop takes up a large amount of potash from the soil. Analyses have shown this to be 600 to 800 pounds per acre, with perhaps half of it removed from the field when the stalks go to the mill. We have a feeling that a large part of the total potash taken up by the plant is taken up in luxury consumption simply because it is available in the soil solution. Surely we do not need to contribute purchased potash fertilizer either to this luxury consumption or to the leachate channels.

We have very little information on the ability of our soils to fix soluble potash salts that may be applied in fertilizer. We have very little evidence showing that the potash supply of any of our soils has actually been increased by the heavy applications of potash that have sometimes been applied in fertilizer, in molasses or in the irrigation water. Hence, unlike phosphate, the supply of which we *can* build up, we are doubtful whether we have built up a potash reserve or even whether we can do so. Thus, to invest money for potash applications beyond the actual needs of the immediate crop would seem most uneconomical, and not to take full advantage of the natural supply of available soil potash would likewise appear to be wasteful.

In the case of potash fertilization then, we have only to consider the needs of the immediate crop when deciding upon our fertilizer policy. If our measures of available potash today indicate an ample supply, we can and should omit potash from the fertilizer applications; if they indicate a probable potash shortage we should be rather liberal with our potash application, for we recognize the full value of potash where sugar-making plants are concerned, and at the present low prices for potash, an expenditure of seven or eight dollars per acre should be able to guarantee us an adequate supply for a good sugar crop.

Nitrogen

As regards nitrogen, I have purposely left this discussion for the last, because it gives us a much more complicated problem to debate than either phosphate or potash. There is no argument with the fact that practically all of our cane crops must have supplementary nitrogen applications, but we do a great deal of guessing when we attempt to state how much supplementary nitrogen we should apply.

Except perhaps where there has been a drought, we do not know that nitrogen, non-utilized from an application to a previous cane crop, has remained in the soil and is available for the following crop. Where cane lands contain ample organic matter and receive a considerable amount of water, excess soluble nitrogen applications have a way of simply disappearing. Thus it appears problematical that we can build up any so-called nitrogen reserve in our soils, and as in the case of potash, our nitrogen problem becomes one of simply feeding the immediate cane crop with its requirements for maximum sugar production.

Our greatest concern, as we have attempted to decide how much nitrogen to apply, has been to avoid having an excessive amount of available nitrogen in the soil (especially close to harvest time) because of its detrimental effect, both directly and indirectly, on the cane quality.

As a rough guide only, we have made use of the amount of nitrogen as found by chemical analyses to be contained in a ton of cane, as the approximate amount that should be furnished the crop in the form of some nitrogen fertilizer salt. This has varied from about 2½ to 3½ pounds of nitrogen per ton of cane that we are expecting to harvest. Some of our previous studies have indicated that about 150 pounds of nitrogen were taken up by a fast-growing cane crop by the time that crop was 8 or 9 months old, and seldom have we provided our short crops with less than this amount of nitrogen in their fertilizer. After this "boom stage" period of growth, the further uptake of nitrogen does not exceed perhaps 5 to 10 pounds per month.

Amounts-of-nitrogen field experiments have indicated an optimum amount for one crop that has been excessive or insufficient on the following crop. It is my belief that such discrepancies are due chiefly to differences in the amounts of the available nitrogen in the soil resulting from the microbiological activity there. Whereas we have usually given some consideration to the amounts of available phosphate and potash in our soils when deciding what amounts of these minerals we would apply as fertilizer, we have never given the same consideration to the available nitrogen content of our soil. It is quite true that available soil nitrogen is an extremely complex and elusive material to determine, but an estimate of water-soluble forms of nitrogen alone should show sufficient qualitative differences in the available soil nitrogen content as of time of sampling, to make it possible for us to change a proposed application to fit the condition we find. I need only to cite an example or two to indicate the economies that could result from a more careful study of the specific nitrogen needs for our cane crops:

(1) If, after a crop had been supplied with 200 pounds of its scheduled 250 pounds of nitrogen, I were to suggest that another 100 pounds be given instead of the 50-pound balance as planned for the second season, I would immediately be challenged with a statement that such an application would ruin the juice, give less sugar, and increase the cost. Yet it is quite possible that at the very time the 50-pound second-season application is made, there may also be another 50 or 100 pounds of available nitrogen already present in the soil. In which event, we might withhold our proposed application to good advantage.

(2) We have tested soils in our Mitscherlich department, taken from fields immediately after harvest, that showed well over 200 pounds of available nitrogen per acre-foot; these fields had produced a good crop of cane from fertilizer applications that supplied 200 or more pounds of nitrogen. An economy might have been possible in these cases.

(3) Where heavy applications of filter cake and/or molasses have been made, a nitrogen economy is possible if soil conditions are favorable for the microbiological activity that will break down the protein nitrogen compounds therein. In general, we have failed to make allowance in our fertilizer applications for the nitrogen content of these mill by-products which carry approximately 10 pounds per ton. When

these mill by-product applications are heavy (10 to 20 tons per acre) the nitrogen contained therein may be quite a factor in affecting the ultimate sugar yield secured, especially where no cognizance is taken of the nitrogen content thereof that may be made available to the crop.

(4) With the advent of many new fast-growing cane varieties, with the vigor that such canes have brought from their "wilder" parents, we see the need for a very careful study of the nitrogen requirements for such canes. These fast starting, rapid first-season growers are quite different from the slower starting, fast second-season grower H 109, which has furnished us with most of our experience in determining optimum amounts of nitrogen, and we have just an indication that they are more economical nitrogen feeders. For instance, at Paauhau in 9 out of 12 AN tests, the maximum sugar from POJ 36 cane has come from nitrogen applications at or below 160 pounds, although larger amounts of nitrogen have given larger cane yields. At Wailuku, although two amounts-of-nitrogen tests on POJ 2878 cut at 15 months used 280 pounds of nitrogen to produce 57 tons of cane with 6.9 tons of sugar, and 75 tons of cane with 8.5 tons of sugar respectively, at Hakalau, 18 months old POJ 2878 gave a yield of 92½ tons of cane and 9½ tons of sugar with only 125 pounds of N. As yet we know very little about the optimum N requirements of POJ 2878, 28-1234, 31-1389, 26 Q 2873 and other fast growers. Hence it is important at this time to consider the installation of a considerable number of amounts-of-nitrogen tests on these canes, using in such tests four nitrogen variables at 50-pound differences, within a range that is definitely lower and higher than your present nitrogen practice: 100-150-200-250 pounds or 125-175-225-275 pounds, N.

I shall not discuss at this meeting the guides which have been given us as measures of soil nutrient differences. The field experiments, the Mitscherlich tests, and the various chemical tests of soils and juices are now familiar measures which I feel afford reliable estimates of the available plant food in our soils. With the advent of the new kit test for nitrogen which Dr. Hance has promised us, and the quick methods for analyzing cane juices, we shall be in a better position to determine soil differences and to use our fertilizers to a still better advantage and economy. There is a great deal of work ahead, however, before we shall be confident that we know how to interpret the results from the use of these new tools.

So far this discussion has concerned itself almost entirely with a determination of the need to apply various plant nutrients. The question of what form of fertilizer to use has quite generally resolved itself into a consideration of cost first, and theoretical suitability second. I shall not attempt to discuss this as a permanent policy at this time. In the case of our sugar crop a definite agricultural superiority of the various soluble potash and nitrogen carriers has rarely been established, and except on the more acid soil types, the water-soluble forms of phosphate are undoubtedly the most efficient, but of the several water-soluble phosphates, we have little proof of the superiority of one over any other.

We see little if any recent change in the time or in the method of applying fertilizer. If we are to reduce our total nitrogen application, we shall have a moot point to determine, i. e., whether to proportionally reduce the amount given at each application, or whether to drop out one of the applications entirely, and if the latter, then

which one. Our nitrogen "kit" test may be expected to help us to answer this question.

It is very evident that the plantation agriculturist is going to play a more important part in getting at the facts that will be used as the basis for this present trend of differential fertilization. He will need to develop a technique of field control that will enable him to be constantly on the lookout for changes in the status of the soil nutrients. With such a control, we may expect to eliminate still more of the guess work and develop a still more efficient and economic usage of commercial fertilizers.

An Improved Type of Hogpen

Submitted herewith are a set of photographs showing in detail the new concrete hogpens recently built by James Webster, manager, Pepeekeo Sugar Company.

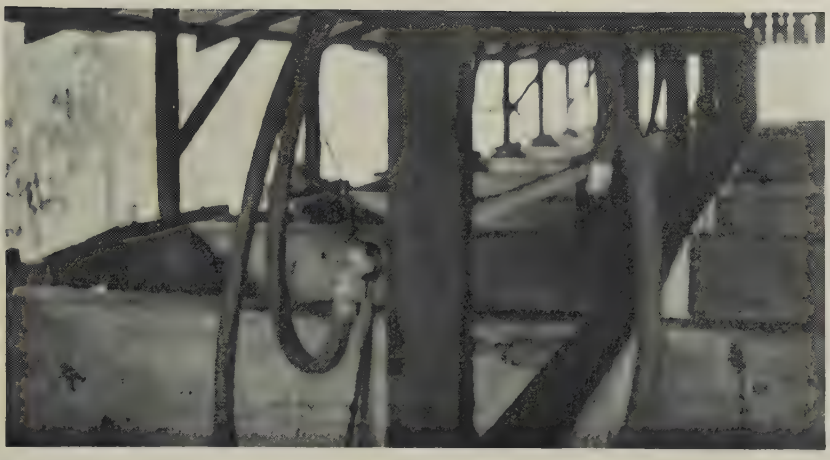
The photographs speak for themselves yet a few notes are in order. The building contains 22 pens, each 6 feet by 8 feet. The walls are 2.9 feet high. Each pen has a concrete floor with a slight slope to a corner where an outlet opens to a concrete drain. This drain empties into the sea over the cliff some fifty feet distant.

Water is piped through the building and a hose connection is made to serve each set of four pens. Thus the pens are flushed frequently and the building is kept clean.

The pens are rented to plantation employees at a low rate.

Acknowledgment is made to Mr. Webster for his courtesy in making the details of his project available to the industry.

S. M. M.



Plantation Fertilizer Practices

A CORRECTION

We issue herewith a corrected and more complete set of fertilizer schedules used at Oahu Sugar Company, Ltd., during 1934, which are intended to replace the schedules shown on page 54 of *The Hawaiian Planters' Record,* Vol. XXXIX, First Quarter, 1935.

D. S. J. and R. J. B.

List of Abbreviations Used

A.S.=Ammonium Sulfate.
N.S.=Nitrate of Soda.
A. P. "B."=Ammonium Phosphate "B."
A–14, A–22, A– 9 }=Mixed Fertilizers

KEY

Kind of Fertilizer	N	P_2O_5	K_2O
	— %	— %	— %
	—# P.A.	—# P.A.	—# P.A.	—# Per Acre

A-14 OAHU SUGAR CO.		
N	7	6.0 Am. .5 Nit. .5 Organic
P_2O_5	20.5	3 Bone 17.5 Am. Phos & Super
K_2O	17	Sulfate & Nitrate
	44.5	

A-22 OAHU SUGAR CO.		
N	6	2.75 Am. 2.75 Nit. .50 Organic
P_2O_5	20	3.0 Bone 17.0 Am. Phos. & Super
K_2O	12	Sulfate & Nitrate
	38	

A-9 OAHU SUGAR CO.		
N	3	2.5 Am. .5 Organic
P_2O_5	15	3.0 Bone 12.0 Am. Phos. & Super
K_2O	28	Sulfate
	46	

OAHU SUGAR CO.

I - LONG-PLANT FIELDS
A - Lowland fields - Spring started: Feb.-Mar.

①	A-14 500	7 35	20.5 102.5	17 85	FIRST SEASON: With seed
②	A-14 600	7 42	20.5 123	17 102	8-12 Weeks after ①
③	A.S. 350	20.5 71.7			May - June
④	N.S. 500	15.5 77.5			SECOND SEASON:- Feb. - March
⑤	N.S. 375	15.5 58.1			March - April
Total		284.3	225.5	187	

I - LONG-PLANT FIELDS
B - Lowland fields - Summer Started: April - June

①	A-14 500	7 35	20.5 102.5	17 85	FIRST SEASON: With seed
②	A-14 600	7 42	20.5 123	17 102	6-8 Weeks after ①
③	A.S. 350	20.5 71.7			June - July
④	N.S. 375	15.5 58.1			SECOND SEASON:- Feb. - March
⑤	N.S. 500	15.5 77.5			March - April
Total		284.3	225.5	187	

I - LONG-PLANT FIELDS
C - Middle Belt fields - Spring started: March - April

①	A-14 500	7 35	20.5 102.5	17 85	FIRST SEASON: With seed
②	A-14 600	7 42	20.5 123	17 102	6-10 Weeks after ①
③	A.S. 350	20.5 71.7			June - July
④	N.S. 375	15.5 58.1			SECOND SEASON:- Feb. - March
⑤	N.S. 500	15.5 77.5			March - April
Total		284.3	225.5	187	

I - LONG-PLANT FIELDS
D - Upland fields - Early Summer Started: April - June

①	A-22 500	6 30	20 100	12 60	FIRST SEASON: With seed
②	A-22 600	6 36	20 120	12 72	4-6 Weeks after ①
③	A.P."B" 500	16 80	20 100		June - July
④	N.S. 375	15.5 58.1			SECOND SEASON:- Feb. - March
⑤	N.S. 500	15.5 77.5			March - April
Total		281.6	320	132	

Note:- 400 lbs. of A.S. is substituted for A.P."B" when filter cake is plowed into the field.

I - LONG-PLANT FIELDS
E - Lowland, Coral-Type fields - Summer Started: May - July

①	A-9 400	3 12	15 60	28 112	FIRST SEASON: With seed
②	A.S. 200	20.5 41			Within 1 month
③	A-9 300	3 9	15 45	28 84	" " "
④	A.S. 300	20.5 61.5			Not later than Oct.
⑤	N.S. 500	15.5 77.5			SECOND SEASON: Feb. - March
⑥	N.S. 375	15.5 58.1			March - April
Total		259.1	105	196	

II - LONG-RATOON FIELDS
A - Lowland fields - Early Started: Nov. - Feb.

①	A-14 400	7 28	20.5 82	17 68	FIRST SEASON: Within 2 Weeks
②	A-14 700	7 49	20.5 143.5	17 119	8-12 Weeks after ①
③	A.S. 350	20.5 71.7			May - June
④	N.S. 500	15.5 77.5			SECOND SEASON: Feb. - March
⑤	N.S. 375	15.5 58.1			March - April
Total		284.3	225.5	187	

II - LONG-RATOON FIELDS
B - Lowland fields - Intermediate Started: March - May 15

①	A-14 400	7 28	20.5 82	17 68	FIRST SEASON Within 1 week
②	A-14 700	7 49	20.5 143.5	17 119	4-8 Weeks after ①
③	A.S. 350	20.5 71.7			June - July
④	N.S. 500	15.5 77.5			SECOND SEASON Feb. - March
⑤	N.S. 375	15.5 58.1			March - April
Total		284.3	225.5	187	

II - LONG-RATOON FIELDS
C - Lowland fields - Late started: after May 15

①	A-14 1100	7 77	20.5 225.5	17 187	FIRST SEASON Immediately
②	A.S. 350	20.5 71.7			4-6 Weeks after ①
③	N.S. 375	15.5 58.1			SECOND SEASON Feb. - March
④	N.S. 500	15.5 77.5			March - April
Total		284.3	225.5	187	

OAHU SUGAR CO.

II - LONG-RATOON FIELDS
D - Lowland, Coral-type fields

①	A-9	3	15	28	FIRST SEASON: Within 2 weeks
	700	21	105	196	
②	A.S.	20.5			4-6 Weeks after ①
	300	61.5			
③	A.S.	20.5			May - June
	350	71.7			
④	N.S.	15.5			SECOND SEASON: Feb. - March
	375	58.1			
⑤	N.S.	15.5			March - April
	375	58.1			
Total	270.4	105	196		

II - LONG-RATOON FIELDS
E - Middle-belt fields - Intermediate Started: Feb.-April

①	A-14	7	20.5	17	FIRST SEASON: Within 1 week
	400	28	82	68	
②	A-14	7	20.5	17	4-8 Weeks after ①
	700	49	143.5	119	
③	A.S.	20.7			June - July
	350	71.7			
④	N.S.	15.5			SECOND SEASON: Feb.-March
	375	58.1			
⑤	N.S.	15.5			March - April
	500	77.5			
Total	284.3	225.5	187		

II - LONG-RATOON FIELDS
F - Middle-belt fields - Late started: May-June

①	A-14	7	20.5	17	FIRST SEASON: Immediately
	1100	77	225.5	187	
②	A.S.	20.5			2-4 Weeks after ①
	350	71.7			
③	N.S.	15.5			SECOND SEASON: Feb.- March
	375	58.1			
④	N.S.	15.5			March - April
	500	77.5			
Total	284.3	225.5	187		

II - LONG-RATOON FIELDS
G - Upland fields - Intermediate started: Feb.-April Low phosphate and high potash soil

①	A-22	6	20	12	FIRST SEASON: Within 2 weeks
	500	30	100	60	
②	A-22	6	20	12	4-8 Weeks after ①
	600	36	120	72	
③	A.P.B.	16	20		June - July
	500	80	100		
④	N.S.	15.5			SECOND SEASON: Feb. - March
	375	58.1			
⑤	N.S.	15.5			March - April
	500	77.5			
Total	281.6	320	132		

II - LONG-RATOON FIELDS
H - Upland fields - Late started: May - June Low phosphate and high potash soil

①	A-22	6	20	12	FIRST SEASON: Immediately
	1100	66	220	132	
②	A.P.B.	16	20		2-4 Weeks after ①
	500	80	100		
③	N.S.	15.5			SECOND SEASON: Feb.- March
	375	58.1			
④	N.S.	15.5			March - April
	500	77.5			
Total	281.6	320	132		

II - LONG-RATOON FIELDS

Note:- Fields under Groups A, B, C, E and F. Poor spots and pali sections found in the fields of the above groups receive an additional 200 pounds of A-14 fertilizer per acre.

Fields with low potash in the soil receive a potassic-nitrogenous fertilizer in place of Ammonium Sulfate to give the same amount of nitrogen.

III - SHORT-RATOON FIELDS
A - Lowland & Middle-belt fields - Early Started: Nov.-Mar.

①	A-14	7	20.5	17	FIRST SEASON: Within 2 weeks
	400	28	82	68	
②	A.S.	20.5			2-8 Weeks after ①
	350	71.7			
③	A-14	7	20.5	17	3-10 " " ②
	700	49	143.5	119	
④	N.S.	15.5			8-10 " " ③
	375	58.1			
⑤	N.S.	15.5			4-6 " " ④
	375	58.1			
Total	264.9	225.5	187		

III - SHORT-RATOON FIELDS
B - Lowland, Coral-type fields - Intermediate & Late Started

①	A-9	3	15	28	FIRST SEASON: Immediately
	700	21	105	196	
②	A.S.	20.5			Applications are spaced at suitable intervals
	300	61.5			
③	A.S.	20.5			
	300	61.5			
④	A.S.	20.5			
	300	61.5			
⑤	N.S.	15.5			Not later than Oct.
	375	58.1			
Total	263.6	105	196		

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 17, 1934, TO MARCH 13, 1935.

Date	Per Pound	Per Ton	Remarks
Dec. 17, 1934	2.60¢	$52.00	Cubas.
Jan. 2, 1935	2.72	54.40	Cubas.
" 3	2.77	55.40	Puerto Ricos.
" 4	2.822	56.44	Puerto Ricos, 2.80, 2.81, 2.83, 2.85; Cubas, 2.82.
" 5	2.83	56.60	Cubas.
" 7	2.84	56.80	Philippines, 2.83, 2.85; Puerto Ricos, 2.85.
" 8	2.83	56.60	Philippines.
" 9	2.81	56.20	Philippines.
" 10	2.80	56.00	Puerto Ricos, Philippines.
" 11	2.7833	55.67	Philippines, 2.77, 2.78, 2.80; Puerto Ricos, 2.78.
" 12	2.77	55.40	Philippines.
" 14	2.78	55.60	Philippines, 2.77, 2.79.
" 15	2.80	56.00	Philippines.
" 17	2.785	55.70	Philippines, 2.80; Cubas, 2.77.
" 18	2.80	56.00	Puerto Ricos.
" 21	2.78	55.60	Cubas.
" 22	2.80	56.00	Cubas, Puerto Ricos, Philippines.
" 23	2.835	56.70	Philippines, 2.82, 2.85; Puerto Ricos, 2.82.
" 24	2.81	56.20	Puerto Ricos, 2.82; Cubas, 2.80.
" 28	2.79	55.80	Puerto Ricos, 2.78, 2.80; Cubas, 2.78.
" 29	2.77	55.40	Cubas, 2.76, 2.78; Puerto Ricos, 2.76.
" 31	2.78	55.60	Puerto Ricos.
Feb. 1	2.80	56.00	Puerto Ricos, Philippines.
" 4	2.82	56.40	Puerto Ricos.
" 5	2.85	57.00	Puerto Ricos, Philippines, Cubas.
" 7	2.86	57.20	Philippines.
" 8	2.85	57.00	Puerto Ricos.
" 14	2.90	58.00	Philippines, Puerto Ricos.
" 21	2.945	58.90	Cubas, 2.94; Philippines, 2.95; Puerto Ricos, 2.95.
" 23	2.97	59.40	Cubas.
" 26	3.00	60.00	Cubas.
" 27	2.985	59.70	Cubas, 3.00; Puerto Ricos, 2.97.
" 28	2.97	59.40	Puerto Ricos.
Mar. 5	3.00	60.00	Philippines.
" 6	2.99	59.80	Philippines, 2.98; Puerto Ricos, 2.98, 3.00.
" 8	3.00	60.00	Puerto Ricos.
" 11	3.05	61.00	Puerto Ricos.
" 13	3.00	60.00	Cubas, Puerto Ricos.